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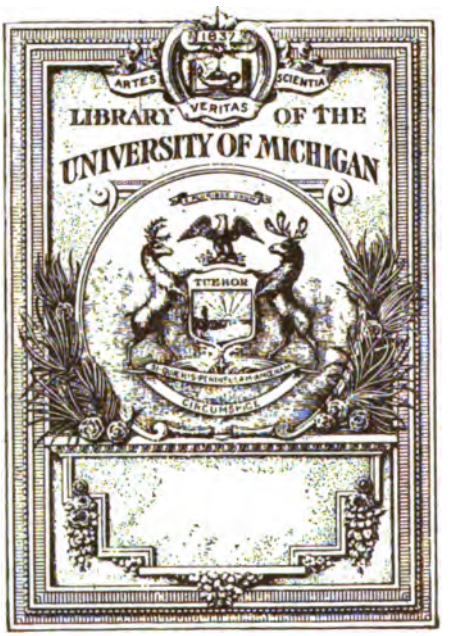

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THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL

BY

HARRY HUSE CAMPBELL

Metallurgical Engineer for The Pennsylvania Steel Co., Maryland Steel Co., and The Spanish American Iron Co.

FOURTH EDITION
THIRD IMPRESSION

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Chem. Lit.
Prof. E. D. Campbell
9th
6-5-1924

To

All Those, Famous or Obscure,

Who, by the Furnace, in the Shop, or at the Desk,

Are Joining Hand and Brain to Solve the

Problems of

The Metallurgic Art,

This Volume is Fraternally Dedicated.

PREFACE TO SECOND EDITION

There are many engineers who wish a brief statement of the art of making steel. It is impossible to do this and at the same time discuss the metallurgical details, for this involves shop language not understood by any except metallurgists. The great electrician whose genius has been crowned with the laurels of two hemispheres referred to the first edition of this book and laughingly, but earnestly, declared that the chapter on the open-hearth was too abstruse for his intellect, while an uneducated open-hearth melter told me he had learned, from that same chapter, how to build a furnace, how to run it, and how to make a good livelihood. The melter understood my language, but to Edison it was a foreign tongue.

Part I is a sort of Introduction for those who are not metallurgists. Part II embraces the ground covered by the first edition of Structural Steel. The text relating to the open-hearth furnace has been condensed from certain papers contributed to the Trans. Am. Inst. Mining Engineers, Vol. XIX, pp. 128 to 187; Vol. XX, pp. 227 to 232, and Vol. XXII, pp. 345 to 511, and 679 to 696, while portions of Chapters XVI, XVII and XVIII appeared in the Trans. Am. Soc. Civil Engineers, April, 1895. The experiments have been conducted at The Pennsylvania Steel Works, of Steelton, Pa., and all details of manufacture have been under my direct observation.

In Part III I have compared the condition of the iron industry in different countries. It would be impossible to describe American districts so fully that every metallurgist would find all the information he might wish, or even a record of all that he already knows. It would be impossible to tell an English engineer much about those parts of his own country with which he is acquainted. It may be possible, however, to clear the way for a foreigner visiting America, or an American visiting other lands.

Some readers might prefer that less space should be devoted to theoretical matter and more to descriptions of apparatus, but in my opinion the place for such information is in the trade periodicals. It takes so long to print a book that drawings are antiquated when the issue appears, but the fundamental principles of metallurgy remain the same. A book issued in England refers courteously to the former edition of this work, but states that little information is given concerning the practical details of operation. That same book sets forth that an open-hearth furnace is charged by putting the pig-iron in first; that in a twenty-five-ton furnace not over nine men can be employed, even when there are doors on both sides, and that with rapid work it takes two hours to charge a heat. Now those figures are true for the district with which that writer was familiar, but in America the pig-iron is put in last, while at Steelton on a furnace of the size mentioned we use twice the number of men and with good scrap finish the work by charging, by hand labor only, in a period ranging from thirty minutes down to eleven minutes. Of equal value is much of the so-called practical information given in metallurgical treatises.

It only remains to thank many friends, both at home and abroad, for aiding in this work which has been accomplished in the intervals of what I trust is not otherwise an entirely idle life.

H. H. CAMPBELL.

Steelton, Pa., December, 1902.

PREFACE TO FOURTH EDITION

Many changes have been made in preparing the fourth edition. By constant additions the book had grown too big to be convenient, so that every line has been gone over to eliminate unnecessary phrases or words. The detailed calculations by the method of least squares in Chapter XVII has been omitted, and it has been deemed unnecessary to print the Standard Specifications in full, since they are constantly subject to change. On the other hand, much new matter has been added; a new determination of the effect of certain elements upon steel is given in Chapter XVII, and at a hundred places new knowledge has been interpolated as suggested by recent progress, or by friends, both here and abroad, who have volunteered information looking to the improvement of this book.

H. H. CAMPBELL.

Steelton, Pa., October, 1906.

TABLE OF CONTENTS

PART I.

The Main Principles of Iron Metallurgy.

	PAGE
The making of pig-iron	3
The making of wrought-iron	5
A definition of steel	6
The making of crucible steel	7
The acid Bessemer process	7
The basic Bessemer process	9
The open-hearth furnace	11
The acid open-hearth process	12
The basic open-hearth process	15
Segregation	17
The influence of hot working on steel	18
The effect caused by changes in the shape of the test-piece	19
The influence of certain elements upon steel	21
Specifications on structural material	24
Welding	26
Steel castings	26
Inspection	27
Errors in chemical records	31

PART II.

The Metallurgy of Iron and Steel.

CHAPTER I.—PRIMITIVE METHODS OF MAKING IRON.

CHAPTER II.—THE BLAST FURNACE.

SECTION IIa.	General description	37
IIb.	Ore	40
IIc.	Fuel	42
IId.	Amount of ore and fuel required	43
IIe.	Limestone	43
IIf.	Use of burned lime	44
IIg.	The blast	45
IIh.	The temperature obtained with hot blast	46
IIi.	Vapor in the atmosphere	47
IIj.	Metallurgical conditions	49

		PAGE
IIk.	Chemical reactions	53
III.	Utilization and waste of heat	67
IIm.	Tunnel head gases	71
IIn.	Volume and value of gas	73
IIo.	Rough estimate of the volume of the gas	75
IIp.	Rough estimate of the heat value of the gas	76
IIq.	Steam in gas	76
IIr.	Heating the blast	77
IIs.	Combustion of the gas under boilers	77
IIt.	Production of power in steam engines	79
IIu.	Production of power in gas engines	80
IIv.	General conclusions on production of power	80
IIw.	Composition of pig-iron	81
IIx.	Structure of cast-iron	83

CHAPTER III.—WROUGHT-IRON.

SECTION IIIa.	Description of the puddling process	85
IIIb.	Effect of silicon, manganese and carbon	85
IIIc.	Chemical history of sulphur and phosphorus	86
IIId.	The temperature of the furnace	88
IIIe.	Effect of work on wrought-iron	89
IIIf.	Heterogeneity of wrought-iron	89
IIIg.	Conditions affecting welding	90

CHAPTER IV.—STEEL.

CHAPTER V.—HIGH-CARBON STEEL.

SECTION Va.	Manufacture of crucible steel	94
Vb.	Reactions in the crucible	95
Vc.	Specifications on high steel	95
Vd.	Manufacture of high steel in the open hearth	97

CHAPTER VI.—THE ACID BESSEMER PROCESS.

SECTION VIa.	Construction of a converter	100
VIb.	Chemical history of a charge	102
VIc.	Variations due to different contents of silicol	103
VId.	Swedish practice	104
VIe.	History of the slag	105
VIf.	Loss in blowing	107
VIg.	Calorific history	108
VIh.	Direct metal	108
VIi.	Cupola metal	110
VIj.	Factors affecting the calorific history	110
VIk.	Recarburization	112

CHAPTER VII.—THE BASIC BESSEMER PROCESS.

		PAGE
SECTION VIIa.	Outline of the basic Bessemer process	113
VIIb.	Elimination of phosphorus	114
VIIc.	Amount of lime required	115
VIId.	Chemical reactions	116
VIIe.	Elimination of sulphur	117
VIIf.	Calorific equation	119
VIIg.	Recarburization	120

CHAPTER VIII.—THE OPEN-HEARTH FURNACE.

SECTION VIIIa.	Description of a regenerative furnace	122
VIIIb.	Quality of the gas required	123
VIIIc.	Construction of a furnace	125
VIIId.	Tilting open-hearth furnace	132
VIIIe.	Method of charging	143
VIIIf.	Ports	144
VIIIg.	Valves	144
VIIIh.	Regulation of the temperature	146
VIIIi.	Calorific equation	148

CHAPTER IX.—FUEL.

SECTION IXa.	The combustion of fuel	158
IXb.	Producers	160
IXc.	Miscellaneous fuels	167
IXd.	Heating furnaces	170
IXe.	Coke ovens	173
IXf.	Coal washing	178

CHAPTER X.—THE ACID OPEN-HEARTH PROCESS.

SECTION Xa.	Nature of the charge in a steel melting furnace.	179
Xb.	Chemical history during melting	180
Xc.	Chemical history after melting	181
Xd.	Quantitative calculations on slags	183
Xe.	Reduction of iron ore when added to a charge	184
Xf.	Pig and ore process	184
Xg.	Conditions modifying the product	185
Xh.	Sulphur and phosphorus	187
Xi.	Method of making tests	187
Xj.	Recarburization	188

CHAPTER XI.—THE BASIC OPEN-HEARTH PROCESS.

SECTION XIa.	Construction of a basic open-hearth bottom	190
XIb.	Functions of the basic additions	190

		PAGE
XIc.	Use of ore mixed with the charge	192
XId.	Chemical history, no ore mixed with stock	192
XIe.	Elimination of phosphorus during melting	193
XIf.	Composition of the slag after melting	198
XIg.	Relative value of different limes	194
XIh.	Basic open-hearth slags	195
XIi.	Automatic regulation of fluidity in slags	197
XIj.	Determining chemical conditions in slags	199
XIk.	Elimination of sulphur	200
XIl.	Removal of the slag after melting	204
XIm.	Automatic formation of a slag of a given composition	204
XIn.	Recarburization and rephosphorization	205

CHAPTER XII.—SPECIAL METHODS OF MANUFACTURE AND SOME ITEMS AFFECTING THE COSTS.

SECTION XIIa.	Low phosphorus acid open-hearth steel at Steelton	207
XIIb.	The pig and ore basic process	211
XIIc.	The Talbot process	213
XIId.	The Bertrand Thiel process	216
XIIe.	The heat absorbed by the reduction of iron ore	219
XIIf.	Ore needed to reduce a bath of pig-iron	224
XIIg.	The gain in weight by reduction of iron ore	228
XIIh.	The duplex process	231

CHAPTER XIII.—SEGREGATION AND HOMOGENEITY.

SECTION XIIIa.	Cause of segregation	234
XIIIb.	Segregation in steel castings	237
XIIIc.	Segregation in plate ingots	239
XIIId.	Homogeneity in plates	240
XIIIe.	Acid rivet and angle steel	247
XIIIf.	High-carbon steel	249
XIIIg.	Acid open-hearth nickel steel	250
XIIIh.	Investigations on Swedish steel	254

CHAPTER XIV.—INFLUENCE OF HOT WORKING ON STEEL.

SECTION XIVa.	Effect of thickness upon the physical properties.	257
XIVb.	Discussion of Riley's investigations on plates	258
XIVc.	Amount of work necessary to obtain good results	259
XIVd.	Experiments on forgings	263
XIVe.	Tests on Pennsylvania Steel Company angles	264
XIVf.	Comparison of the strength of angles with that of the preliminary test-piece	266

PAGE

XIVg. Physical properties of the Pennsylvania Steel Company steels of various compositions..... 267
XIVh. Properties of hand and guide rounds..... 268
XIVi. Effect of variations in the details of plate rolling 269
XIVj. Physical properties of plates and angles..... 271
XIVk. Effect of thickness on the properties of plates. 272

CHAPTER XV.—HEAT TREATMENT.

SECTION XVa. Effect of annealing on rolled bars..... 274
XVb. Annealing bars rolled at different temperatures. 278
XVc. Effect of annealing on bars..... 279
XVd. Effect of annealing on plates..... 280
XVe. Effect of annealing eye-bar flats..... 282
XVf. Methods of annealing..... 282
XVg. Further experiments on annealing rolled bars.. 284
XVh. The determination of temperature..... 285
XVi. Definition of the term "critical point"..... 287
XVj. Different structures seen under the microscope.. 296
XVk. Effect of work on soft steel and forging steel.... 302
XVl. Effect of work upon the structure of rails..... 303
XVm. Effect of heat treatment upon castings..... 305
XVn. Effect of heat treatment upon rolled material... 309
XVo. Theories regarding the structure of steel..... 310

CHAPTER XVI.—THE HISTORY AND SHAPE OF THE TEST-PIECE.

SECTION XVIa. Difference between the surface and the interior. 313
XVIb. Strips cut from eye-bar flats..... 314
XVIc. Comparison of longitudinal and transverse tests. 314
XVId. Comparison of parallel and grooved tests..... 316
XVIe. Effect of shoulders at the ends of test-pieces.... 316
XVIf. The preliminary test-piece..... 318
XVIg. Comparative properties of rounds and flats.... 319
XVIh. Effect of diameter upon the physical properties. 322
XVIi. Influence of the width of the test-piece..... 325
XVIj. Influence of the length of the test-piece..... 327
XVIk. Tests on eye-bars..... 330
XVIl. Effect of rest after rolling..... 337
XVIm. Errors in determining the physical properties.. 337
XVIn. Effect of variation in the pulling speed..... 342

CHAPTER XVII.—THE INFLUENCE OF CERTAIN ELEMENTS ON THE PHYSICAL PROPERTIES OF STEEL.

SECTION XVIIa. Effect of carbon..... 343
XVIIb. Effect of silicon..... 344
XVIIc. Effect of manganese..... 350
XVIId. Effect of sulphur..... 355

PAGE

XVIIe. Effect of phosphorus..... 356
XVIIf. Effect of copper..... 358
XVIIg. Effect of aluminum..... 361
XVIIh. Effect of arsenic..... 363
XVIIi. Effect of nickel, tungsten and chromium..... 364
XVIIj. Effect of oxygen..... 366
XVIIk. Investigations by Webster..... 368
XVIIl. Values of the elements as found by the method of least squares..... 368
XVIIm. Values of the elements as found by plotting... 369

CHAPTER XVIII.—CLASSIFICATION OF STRUCTURAL STEEL.

SECTION XVIIIa. Influence of the method of manufacture..... 392
XVIIIb. Chemical specifications..... 394
XVIIIc. Use of soft steel in structural work..... 396
XVIIId. Tests on plates..... 398
XVIIIe. Standard size of test-pieces..... 399
XVIIIf. The quench test..... 400
XVIIIg. Standard specifications..... 401

CHAPTER XIX.—WELDING.

SECTION XIXa. Influence of structure on the welding properties. 402
XIXb. Tensile tests on welded bars of steel and iron... 403
XIXc. Influence of metalloids upon welding..... 407

CHAPTER XX.—STEEL CASTINGS.

SECTION XXa. Definition of a steel casting..... 409
XXb. Methods of manufacture..... 410
XXc. Blow-holes 412
XXd. Phosphorus and sulphur in steel castings..... 413
XXe. Effect of silicon, manganese and aluminum. ... 413
XXf. Physical tests on soft steel castings..... 414
XXg. Physical tests on medium hard steel castings... 417

PART III.

The Iron Industry of the Leading Nations.

CHAPTER XXI.—FACTORS IN INDUSTRIAL COMPETITION.

SECTION XXIa. The question of management..... 421
XXIb. The question of employer and employed..... 426
XXIc. The question of tariffs..... 435

CHAPTER XXII.—THE UNITED STATES.

SECTION XXIIa. General view..... 441
XXIIb. Coal 447

PAGE

XXIIc. Lake Superior 456
XXIId. Pittsburg 468
XXIIe. Chicago 473
XXIIf. Alabama 477
XXIIg. Johnstown 483
XXIIh. Steelton 483
XXIIi. Sparrow's Point 485
XXIIj. Lake Erie 489
XXIIk. Colorado 492
XXIIl. Eastern Pennsylvania 493
XXIIm. New Jersey, New York and New England 494

CHAPTER XXIII.—GREAT BRITAIN.

SECTION XXIIIa. General view 496
XXIIIb. Northeast Coast 503
XXIIIc. Scotland 511
XXIIId. South Wales 514
XXIIIe. Lancashire and Cumberland 517
XXIIIf. South Yorkshire 520
XXIIIg. Staffordshire 521
XXIIIh. The Eastern Central District 522

CHAPTER XXIV.—GERMANY.

SECTION XXIVa. Statistics 525
XXIVb. Lothringen and Luxemburg 527
XXIVc. The Ruhr 537
XXIVd. Silesia 544
XXIVe. The Saar 547
XXIVf. Aachen 548
XXIVg. Ilsede and Peine 549
XXIVh. Saxony 550
XXIVi. Siegen 550
XXIVj. Osnabruck 551
XXIVk. Bavaria 551
XXIVl. The Lahn 552
XXIVm. Pommerania 552

CHAPTER XXV.—FRANCE.

SECTION XXVa. General view 553
XXVb. The East 553
XXVc. The North 558
XXVd. The Centre 559
XXVe. The South 561
XXVf. The Northwest and the Southwest 561

CHAPTER XXVI.—RUSSIA.

PAGE

SECTION XXVIa. General view 563
XXVIb. The South 567
XXVIc. The Urals 570
XXVId. Poland 573
XXVIe. The Centre 574
XXVIf. The North 575

CHAPTER XXVII.—AUSTRIA.

SECTION XXVIIa. General view 576
XXVIIb. Bohemia 579
XXVIIc. Moravia and Silesia 580
XXVIId. Styria 582
XXVIIe. Hungary 584

CHAPTER XXVIII.—BELGIUM. 587

CHAPTER XXIX.—SWEDEN. 593

CHAPTER XXX.—SPAIN. 601

CHAPTER XXXI.—ITALY. 605

CHAPTER XXXII.—CANADA. 607

CHAPTER XXXIII.—STATISTICS. 609

APPENDIX.

Value of certain factors used in iron metallurgy 617
Content of metallic iron in pure compounds of iron 617
Reactions in open-hearth furnaces 617
Properties of air 617
Comparison of English and metric systems 618
Gravimetric and calorific values 618

INDEX TO TABLES

BLAST FURNACE.

		PAGE
II-A	Blast-furnace slags	50
II-B	Practice at Middlesbro and Pittsburg	66
II-C	Distribution of calorific energy	67
II-D	General equation	69
II-E	Method of calculating the composition and value of	72
II-F	Composition and value of the gas	74
II-G	Data on products of combustion	77
II-H	Loss of heat in products of combustion	79
II-I	Composition of pig-iron and spiegel	83

WROUGHT-IRON.

III-A	Elimination of metalloids in puddling	87
III-B	Composition of puddle cinder	89
III-C	Plates from shear and universal mills	90
III-D	Irregularity of wrought-iron	91

HIGH STEEL.

V-A	Steel not according to specification	96
V-B	Clippings from top and bottom of ingot	97
V-C	Variations in Swedish metal	98
V-D	Variations in one lot of crucible steel	99

ACID BESSEMER.

VI-A	Chemical history of a charge	102
VI-B	Manganiferous irons and slags	104
VI-C	Steel from manganiferous irons	105
VI-D	American Bessemer slags	106
VI-E	Calorific history	109

BASIC BESSEMER.

VII-A	Metal, slag and gases	116
VII-B	Reduction of manganese from slag	117
VII-C	High sulphur iron in basic converter	118
VII-D	Calorific equation of the basic Bessemer process	120

OPEN-HEARTH FURNACE.

		PAGE
VIII-A	Distribution of heat in the producer	153
VIII-B	Distribution of heat in the furnace	155
VIII-C	Distribution of heat in producer and furnace combined	157

FUEL.

IX-A	Products of combustion of hard and soft coal	159
IX-B	Loss of heat in products of combustion	160
IX-C	Heat lost in producer ash	164
IX-D	Heat lost by CO_2 in gas	165
IX-E	Waste gases from reverberatory furnaces	172
IX-F	Calculations on waste gases from reverberatory furnaces	172

ACID OPEN-HEARTH.

X-A	Elimination of metalloids in an open-hearth charge	181
X-B	History of metal and slag in an acid furnace	182
X-C	Reduction of ore	183
X-D	Slag and metal at different periods	184

BASIC OPEN-HEARTH.

XI-A	Composition of slag and metal from seventeen heats	193
XI-B	Elimination of phosphorus and carbon during melting	194
XI-C	Relative value of limes with 3.0 and 7.0 per cent. of SiO_2	195
XI-D	Relation between SiO_2 and FeO in basic slags	198
XI-E	Maxima and minima in the heats composing Table XI-D	198
XI-F	Unstable basic open-hearth slags	200
XI-G	Normal basic open-hearth slags	200
XI-H	Basic open-hearth slags after melting	201
XI-I	Basic open-hearth slags before recarburizer	202
XI-J	Elimination of sulphur by calcium chloride	203
XI-K	Data on the use of calcium chloride	203
XI-L	Slag analyses of twenty-seven basic heats	205

CONSIDERATION OF CERTAIN SPECIAL METHODS AND SOME ITEMS AFFECTING THE COST OF MANUFACTURE.

XII-A	Composition of metal and slag in making transfer steel	209
XII-B	Comparison of data in Tables X-B and XII-A	210
XII-C	Record of "all pig" basic open-hearth heats at Steelton	212
XII-D	Reactions in the Talbot process	214
XII-E	Elimination of sulphur in the Talbot furnace	215
XII-F	Representative heats at Kladno	219
XII-G	Oxygen needed for a pig-iron charge	225
XII-H	Oxygen used in the Talbot furnace	226
XII-I	Silica in the Talbot furnace	227

		PAGE
XII-J	Oxygen in the Talbot furnace	227
XII-K	Distribution of the metallic iron in the Talbot furnace	229
	SEGREGATION.	
XIII-A	Extreme segregation in pipe cavity	237
XIII-B	Composition of a twenty-inch steel roll cast in sand	238
XIII-C	Segregation in plate ingots	238
XIII-D	Segregation in large ingots	239
XIII-E	Plates rolled from ordinary plate ingots	241
XIII-F	Universal mill plates rolled from slabs	242
XIII-G	Annealed bars cut from plates	243
XIII-H	Variations in carbon due to analytical errors	247
XIII-I	Tests from different parts of the same heats	248
XIII-J	Composition of rods from heat 10,168	250
XIII-K	Angles rolled from acid open-hearth steel	251
XIII-L	Distribution of elements in high carbon ingot	252
XIII-M	Distribution of elements in high carbon blooms	253
XIII-N	Composition of the liquid interior of an ingot	253
XIII-O	Homogeneity of acid open-hearth nickel steel	254
XIII-P	Segregation in Swedish ingots	255
	HOT WORKING.	
XIV-A	Results on different thicknesses of steel plates	259
XIV-B	Results on plates from different sized ingots	259
XIV-C	Influence of thickness, the reduction in rolling being constant	261
XIV-D	Influence of thickness, all pieces being rolled from billets of one size	262
XIV-E	Effect of hammering acid open-hearth steel	262
XIV-F	Physical properties of thick and thin angles	264
XIV-G	Comparison of angles and preliminary test	265
XIV-H	Physical properties of steel angles	266
XIV-I	Effect of flats finished at different temperatures	268
XIV-J	Comparison of hand rounds and guide rounds	268
XIV-K	Changes caused by variations in the methods of rolling; classified by preliminary test	269
XIV-L	Changes caused by variations in the methods of rolling; classified by finished plate	270
XIV-M	Comparison of angles and sheared plates	271
	HEAT TREATMENT.	
XV-A	Effect of annealing on rounds and flats	275
XV-B	Comparison of the Bessemer bars in Table XV-A	276
XV-C	Comparison of the open-hearth bars in Table XV-A	277
XV-D	Effect of annealing acid open-hearth rolled steel bars	278
XV-E	Effect of annealing bars of different thickness, the percentage of reduction in rolling being constant	279

		PAGE
XV-F	Effect of annealing bars of different thickness, all pieces being rolled from billets of one size	280
XV-G	Rolled plates made alike by annealing	281
XV-H	Comparative tests of eye-bar steel	282
XV-I	Comparison of natural and annealed flat bars	283
XV-J	Effect of annealing at about 800° C	284
XV-K	Comparison of natural and annealed bars in Table XV-J	285
XV-L	Theoretical microstructure of carbon steels	300
XV-M	Microstructural composition of quenched carbon steels	300

HISTORY OF TEST-PIECE.

XVI-A	Comparison of three-quarters-inch rolled rounds and seven-eighths-inch rounds turned down to three-quarters inch	313
XVI-B	Properties of test-pieces cut from forged rounds	314
XVI-C	Properties of test-pieces cut from rolled flats	315
XVI-D	Comparison of eye-bar flats with the preliminary test	316
XVI-E	Comparison of longitudinal and transverse tests	316
XVI-F	Comparison of parallel and grooved tests	317
XVI-G	Ultimate strength of two-inch tests and eight-inch parallel sided tests	317
XVI-H	Comparison of angles with the preliminary test	318
XVI-I	Comparative physical properties of rounds and flats	320
XVI-J	Properties of round and flat bars, natural and annealed	321
XVI-K	Physical properties of rounds of different diameters	323
XVI-L	Effect of changes in the width of the test-piece	324
XVI-M	Influence of the width upon the elongation (Barba)	326
XVI-N	Effect of width upon the elongation (Custer)	326
XVI-O	Influence of the length of the test-piece	327
XVI-P	Influence of the length upon the elongation (Barba)	329
XVI-Q	Physical properties of eye-bars	331
XVI-R	Physical properties of eye-bars	332
XVI-S	Properties of eye-bars, classified according to length	333
XVI-T	Proportion of rejections caused by applying a sliding scale of elongation to the eye-bar records in Table XVI-Q	335
XVI-U	Physical changes in steel by rest after rolling	336
XVI-V	Physical properties determined by different laboratories	338
XVI-W	Parallel determinations of the elastic limit by the autographic device and by the drop of the beam	340
XVI-X	Effect of the pulling speed of testing machine	341

INFLUENCE OF ELEMENTS.

XVII-A	Properties of silicon steels	345
XVII-B	Influence of silicon upon tensile strength	346

		PAGE
XVII-C	Steels containing from .01 to .50 per cent. of silicon....	347
XVII-D	Comparison of low-silicon and high-silicon steels.....	348
XVII-E	Effect of manganese.....	352
XVII-F	Properties of steel with 1.00 per cent. of manganese....	353
XVII-G	Properties of forged steel with high manganese.....	354
XVII-H	Effect of phosphorus.....	357
XVII-I	Effect of copper.....	360
XVII-J	Physical properties of aluminum steel.....	361
XVII-K	Effect of aluminum.....	363
XVII-L	Physical qualities of nickel steel.....	365
XVII-M	Data on very soft basic steel.....	367
XVII-N	Groups used to find effect of carbon, phosphorus and manganese	371
XVII-O	Combination of data in Table XVII-N by groups of three.	372
XVII-P	Classification of acid heats according to phosphorus....	374
XVII-Q	Classification of acid heats according to manganese.....	377
XVII-R	Effect of manganese upon acid steel.....	378
XVII-S	Classification of acid heats according to sulphur..	379
XVII-T	Effect of carbon upon acid steel.....	380
XVII-U	Classification of basic steel according to manganese.....	381
XVII-V	Effect of manganese upon basic steel.....	381
XVII-W	Classification of basic steel according to sulphur.....	384
XVII-X	Effect of carbon upon basic steel.....	385
XVII-Y	Comparison of actual and calculated strengths.....	387
XVII-Z	Subdivision of groups in Table XVII-Y.....	390

CLASSIFICATION OF STEEL.

XVIII-A	Rise in elastic ratio with fall in ultimate strength.....	397
XVIII-B	Calculation of 12 $\sqrt{f}$ for different diameters.....	400

WELDING.

XIX-A	Tests on welded bars of steel and wrought-iron.....	404
XIX-B	Welding tests by The Royal Prussian Testing Institute...	406

CASTINGS.

XX-A	Comparison of castings and rolled bars.....	416
XX-B	Properties of castings of medium hard steel.....	417

AMERICAN VS. EUROPEAN PRACTICE.

XXI-A	Miles of railway in operation in 1902.....	423

UNITED STATES.

XXII-A	Production of pig-iron and steel in 1901.....	442
XXII-B	Production of steel from 1867.....	444

		PAGE
XXII-C	Production of steel in the United States and Great Britain	445
XXII-D	Kinds of steel made in the United States and Great Britain	445
XXII-E	Imports of iron ore	447
XXII-F	Production of coal and coke in 1902	453
XXII-G	Output of the principal coal fields in 1902	454
XXII-H	Output of soft coal in Pennsylvania in 1902	454
XXII-I	Coke records for Pennsylvania and West Virginia in 1903	455
XXII-J	American ore supply	457
XXII-K	Large producers of ore in Lake Superior district	459
XXII-L	Price of Lake Superior ore	461
XXII-M	Movement of Lake ore	463
XXII-N	Output of pig-iron and steel in Pennsylvania in 1903	469
XXII-O	Large works in the Pittsburg district	472
XXII-P	Number of steel units in the Pittsburg district	473
XXII-Q	Output of pig-iron in Alabama	481
XXII-R	Output of ore in Cuba	488
XXII-S	Plants in Southeastern Pennsylvania	494
XXII-T	Plants in New Jersey, New York and New England	495

GREAT BRITAIN.

XXIII-A	Imports of iron ore	497
XXIII-B	Output of coal, ore, iron and steel	498
XXIII-C	Output of pig-iron	499
XXIII-D	Production of iron ore	500
XXIII-E	Imports of iron ore at different ports	500
XXIII-F	Iron and steel plants on the Northeast Coast	509
XXIII-G	Output of ore and pig-iron on the Northeast Coast	511
XXIII-H	Imports of ore on the Northeast Coast	511
XXIII-I	Production of pig-iron in Scotland	512
XXIII-J	Iron and steel plants in Scotland	513
XXIII-K	Production of ore and pig-iron in Scotland	514
XXIII-L	Imports of ore into Scotland	514
XXIII-M	Iron and steel plants in South Wales	516
XXIII-N	Production of pig-iron on the Bristol Channel	517
XXIII-O	Imports of ore on the Bristol Channel	517
XXIII-P	Iron and steel plants on the West Coast	519
XXIII-Q	Production of ore and pig-iron on the West Coast	519
XXIII-R	Imports of ore on the West Coast	520
XXIII-S	Iron and steel plants in South Yorkshire	520
XXIII-T	Production of pig-iron in South Yorkshire	521
XXIII-U	Production of ore and pig-iron in Staffordshire	522
XXIII-V	Production of ore and pig-iron in Eastern Central England	523
XXIII-W	Production of pig-iron in Central England	524

GERMANY.

		PAGE
XXIV-A	Production of ore and pig iron	525
XXIV-B	Movement of ore	527
XXIV-C	Production of steel	527
XXIV-D	Composition of minette ores	529
XXIV-E	List of works in Lothringen and Luxemburg	536
XXIV-F	Production of coke in Germany	538
XXIV-G	List of works in Westphalia	543
XXIV-H	List of works in Silesia	546
XXIV-I	List of works in Saar District	548
XXIV-J	Composition of Ilsede ores	549

FRANCE.

XXV-A	Production of fuel, ore, iron and steel in France in 1899.	555
XXV-B	List of works in the East of France	558
XXV-C	List of works in the North of France	559
XXV-D	List of works in the Centre of France	560
XXV-E	List of works in the South of France	561
XXV-F	List of works in the Northwest and Southwest of France.	562

RUSSIA.

XXVI-A	Imports of iron, steel and fuel	564
XXVI-B	Production of coal, ore, iron and steel	566
XXVI-C	List of works in South Russia	570
XXVI-D	Imports of iron and fuel at St. Petersburg	575

AUSTRIA.

XXVII-A	Annual output of fuel, ore, pig iron and steel in Austria-Hungary	576
XXVII-B	Production of steel in Austria	578
XXVII-C	List of works in Bohemia	580
XXVII-D	Output of the Silesian coal fields	580
XXVII-E	List of works in Moravia and Silesia	582
XXVII-F	List of works in Styria	584
XXVII-G	Production of coal, ore and pig-iron in Hungary in 1899	585
XXVII-H	Production of steel in Hungary	586

BELGIUM.

XXVIII-A	Production of coal, coke, iron and steel in Belgium	588
XXVIII-B	Important blast furnace plants in Belgium	589

SWEDEN.

XXIX-A	Production of coal, ore, iron and steel in Sweden	593
XXIX-B	List of works in Sweden	600

SPAIN. PAGE

XXX-A Spanish ore production and exports..... 603

ITALY.

XXXI-A Exports of ore from Elba in 1899..... 606

CANADA.

XXXII-A Composition of fuel and ore at Cape Breton..... 608

THE IRON INDUSTRY.

XXXIII-A Discordant data in steel output in Germany..... 610
XXXIII-B Production of pig-iron per capita..... 611
XXXIII-C Pig-iron producing districts of the world..... 613
XXXIII-D Steel producing districts of the world..... 614
XXXIII-E Production of coal, ore, pig-iron and steel in 1903.... 615
XXXIII-F Production of coal by the leading nations..... 615
XXXIII-G Production of iron ore by the leading nations..... 616
XXXIII-H Production of pig-iron by the leading nations..... 616
XXXIII-I Production of steel by the leading nations..... 617

INDEX TO FIGURES

		PAGE
II-A	Blast furnace at Jones & Laughlin's, Pittsburg	38
II-B	Bosh construction at Steelton, Pa.	39
II-C	Blast furnace reactions as determined by the temperature	54
II-D	Chemical reactions in blast furnace	62
VI-A	Section of 18-ton converter, two views	101
VIII-A	Bad type of open-hearth furnace	124
VIII-B	40-ton acid furnace at Steelton, Pa., two views	127, 128
VIII-C	50-ton Campbell basic furnace at Steelton, Pa., three views	129-133
VIII-D	30-ton basic furnace at Donnawitz, Austria, six views	134-139
VIII-E	50-ton basic furnace at Duquesne, Pa., two views	140
VIII-F	50-ton basic furnace at Sharon, Pa., two views	140
VIII-G	Wellman charging machine, two views	143
VIII-H	Valves used at Steelton, two views	145, 146
VIII-I	Forter valve	147
IX-A	Water seal producer, two views	161
IX-B	Semet Solvay coke oven, two views	176
IX-C	Otto Hoffman coke oven	177
XV-A	Variations in the critical points in different steels	288
XV-B	Micro-photographs Nos. 1 to 9	290
XV-C	Micro-photographs Nos. 10 to 18	291
XV-D	Micro-photographs Nos. 19 to 24	292
XV-E	Micro-photographs Nos. 25 to 30	293
XV-F	Micro-photographs Nos. 31 to 36	294
XV-G	Micro-photographs Nos. 37 to 45	295
XV-H	Graphical representation of the phase doctrine	312
XVI-A	Elongation with varying length	328
XVI-B	Curves showing law of elongation of eye-bars	334
XVII-A	Strength of steel	370
XVII-B	Effect of phosphorus on acid steel	373
XVII-C	Effect of manganese on acid steel	376
XVII-D	Effect of sulphur on acid steel	379
XVII-E	Effect of manganese on basic steel	382
XVII-F	Effect of sulphur on basic steel	384
XVII-G	Effect of carbon on acid and basic steel	383

		PAGE
XXII-A	Map of United States, eastern half	449
XXII-A	Map of United States, western half	448
XXII-B	Pennsylvania, West Virginia, Ohio, etc., eastern half	451
XXII-B	Pennsylvania, West Virginia, Ohio, etc., western half	452
XXII-C	Map of lake region	464
XXII-D	Mesabi, Vermilion and Gogebic ranges	465
XXII-E	Marquette and Menominee ranges	466
XXII-F	Map of Allegheny County, Pa	467
XXII-G	Bessemer plant at Edgar Thomson	474
XXII-H	Bessemer plant at South Chicago	475
XXII-I	Rail mill at South Chicago	476
XXII-J	Birmingham ore deposit	480
XXII-K	Bessemer plant at Steelton	486
XXII-L	Open-hearth plant at Steelton	487
XXII-M	Rail mill at Sparrow's Point	490
XXIII-A	Map of Great Britain	501
XXIII-B	Coal fields of Great Britain	502
XXIII-C	Durham coal field	503
XXIII-D	Cleveland ore deposit	504
XXIII-E	Rolling mill of Northeastern Steel Company	510
XXIII-F	Works at Cardiff	515
XXIV-A	Map of Germany	526
XXIV-B	Minette district	528
XXIV-C	Rombach Steel Works	535
XXV-A	Map of France	554
XXV-B	Coal and ore fields of France	556
XXVI-A	Map of Russia	565
XXVI-B	South Russian iron district	568
XXVII-A	Map of Austria	577
XXVIII-A	Map of Belgium	590
XXIX-A	Map of Sweden	594
XXIX-B	Swedish blast furnace	596
XXX-A	Map of Spain	602
XXXIII-A	Production of coal in the leading nations	619
XXXIII-B	Production of ore in the leading nations	620
XXXIII-C	Production of pig-iron in the leading nations	621
XXXIII-D	Production of steel in the leading nations	622

PART I.

INTRODUCTION.

The Main Principles of Iron Metallurgy.

INTRODUCTION.

THE MAKING OF PIG-IRON.

The process of making steel begins by making pig-iron from iron ore. This iron ore is natural iron rust. It is a combination of iron and oxygen, and if we take away the oxygen the iron is left alone. Charcoal or coke or carbon in any form will rob iron ore of its oxygen, and it will do this at a very moderate temperature, the action taking place if the ore and coke are mixed and heated red hot. But it is necessary to do more than this. The iron must be melted and the earthy parts of the ore and coke must be separated from the iron. The operation is conducted in a furnace about one hundred feet high, filled with a mixture of coke, iron ore and limestone, and superheated air is blown in at the bottom. A portion of the coke is burned by the oxygen of the air and serves to maintain the furnace at a high temperature, while another portion is employed in robbing the iron ore of its oxygen.

The air that is blown into the furnace is first heated to a dull red heat by passing it through "stoves." These stoves are in turn heated by burning in them the gases escaping from the top of the furnace. In ancient days these gases were allowed to escape freely, but now the tops are closed tight and all the gas is taken down to the level of the ground, part being used under boilers to generate steam to run the blowing engines, and part in the stoves to preheat the blast.

As the air is red hot when it enters the tuyeres, and as it immediately meets glowing coke which has been heated by its downward passage through the furnace, it follows that a very high temperature must be caused at this point. This region, therefore, immediately about the tuyeres is called the "zone of fusion." It is here that the real melting occurs, but a great deal of the work is done higher up in the furnace, for the gases from this hot zone of fusion ascend through the overlying 70 or 80 feet of stock and heat it to a high temperature, and under these conditions there is a reaction

between the carbon of the gas and the iron ore, whereby the oxygen of the ore unites with the carbon and leaves the iron in the finely divided metallic state known as "spongy iron." The reaction is not complete and a great deal of ore reaches the zone of fusion in a nearly raw state, but in this zone the extremely high temperature quickly completes all reactions; the raw ore is rapidly reduced, the earthy impurities unite with the limestone and are fused into slag, while the metallic iron melts and is collected in the hearth below the tuyeres.

The metal so produced is not pure iron, for while it is in contact with white-hot coke in the furnace, it absorbs a certain amount of carbon. This amount is quite constant, and it is safe to assume that any piece of ordinary pig-iron, no matter what its appearance may be, contains from 3.5 to 4.0 per cent. of carbon. Some of this carbon is chemically combined with the iron, and some is held in suspension as graphite. If a large proportion is combined, the fracture of the iron looks white and the metal is hard and brittle. If a large proportion is in the free state, the fracture will be gray or black, with loose scales of graphite, and the iron is soft and tough. Very slow cooling tends to put the carbon into the condition of graphite, while sudden chilling from the liquid state tends to keep it in combination and give a hard and white iron.

The iron also contains silicon, which is absorbed in the furnace from the ash of the coke. Sometimes this silicon will amount to only one-half of 1 per cent. and sometimes it will be 3 per cent. Usually there will be from 1 to 2 per cent.

A certain small proportion of sulphur will also be present. It is not wanted at all, but there is seldom less than two-hundredths of one per cent., while there may be one-quarter of one per cent., and even more. When there is over one-tenth of one per cent. the iron is apt to be hard and brittle and to have a close and white fracture. In such iron, the silicon is usually low and this contributes to the closeness of the grain.

The percentages of silicon and sulphur that are present in the iron depend in great measure upon the conditions in the blast furnace, and hence may be controlled by the furnaceman. But there is one element which is universally present, over which he has no control. This element is phosphorus. Whatever quantity is present in the ore and fuel will be found in the pig-iron, so that the only way to get an iron low in phosphorus is to get ore and coke

which contain only a small percentage. In irons used for making steel by the usual Bessemer process, the iron is not allowed to contain over one-tenth of one per cent. of phosphorus. For basic steel and for foundry work no fixed limit can be given.

Where great toughness is required in iron castings it is well to use what is called "Bessemer pig-iron," by which term is meant an iron containing not over one-tenth of one per cent. of phosphorus. Such an iron costs very little more than ordinary foundry grades. In other cases a high percentage is desired to confer great fluidity, and irons carrying 3 per cent. of phosphorus are in demand, a certain proportion of such metal being used in making intricate castings where the metal must accurately fill every corner of the mold.

Pure iron itself is very difficult to melt; it is soft, tough and malleable both hot and cold, but the elements above described, preëminently the presence of nearly 4 per cent. of carbon, change its character completely in the following ways:

(1) It is more fusible.

(2) It is brittle.

(3) It cannot be forged either hot or cold.

Thus we have what the general public calls cast-iron. In the trade, however, this term is applied to it only after it has been melted again and cast into some finished form. The product of the blast-furnace is always spoken of as pig-iron. It is the foundation stone of all the iron industry; it is one of the great staples in the commerce of the world. The foundryman makes from it his kettles and stoves; the puddler refines it and supplies the village blacksmith with bars for chains and horseshoes; the steel maker transmutes it into watch-springs and cannon.

THE MAKING OF WROUGHT-IRON.

When the Bessemer process of steel making was invented it was confidently predicted that it sounded the death-knell of the puddling furnace, but although there have been several announcements of the funeral, the great event has never actually occurred. There seem to be a few places where wrought-iron is needed, and there are many more places where the blacksmith and the machinist find steel unsatisfactory, because they do not know anything about the metal and refuse to learn, usually stating that they have been "working long enough to know."

Wrought-iron is made by melting pig-iron in contact with iron ore and burning out the silicon, carbon and phosphorus, leaving metallic iron. This iron is not in a melted state when finished, for the temperature of the furnace is not sufficiently high to keep it fluid after the carbon has burned. It is in a pasty condition and is mixed with slag and when taken out of the furnace is a honeycomb of iron, with each cell full of melted lava, and this honeycomb is squeezed and rolled until most of the slag is worked out and the iron framework is welded together into a compact mass. The bars are rough and full of flaws and are regarded as an intermediate product. This "muck bar" is then cut up and "piled" and heated to a welding heat and rolled again, and this time the bar is clean and becomes the "merchant iron" of commerce.

The previous description refers to the use of pig-iron only, but in many works this practice is modified by using scrap of various kinds, especially steel turnings from machine shops. Oftentimes almost the entire charge is made of cast-iron borings and steel turnings, although a certain amount of larger steel scrap is generally used to make the ball hold together. In making the pile for the second rolling a certain proportion of soft steel scrap is often used, as this welds up with the rest, so as to be practically the same, and this increases the tensile strength of the bar. The main principles of the process, however, remain the same in all its forms.

A DEFINITION OF STEEL.

In the olden time all kinds of steel, whether made in the crucible, in the cementation chamber, or in the puddle furnace, contained carbon enough to make them suitable for cutting tools when hardened in water, and the steels that were made in the Bessemer converter during the early days of its history were all more or less hard, much of it being used for tools; consequently the metal made in the converter was rightly called Bessemer *steel.*

As time went on and the cost of the operation was reduced below that of making wrought-iron, a great deal of very soft metal was made in the converter and in the open-hearth furnace. This new metal did not fill the old definition of steel, but it was impossible to draw any line between the steel used for rails and that used for forgings, and it was impossible to draw a line between the metal used for forgings and that used for boiler plate, and as it was impossible to do this, practical men in America and England did

not try to do it, but called everything that was made in the Bessemer converter, or in the open-hearth furnace, or in the crucible, by the name "steel."

A few scientific committees tried to make new names, but their labors came to naught in England and America. In Germany the committees had their way for many years, and the soft metals of the converter and the open-hearth were called ingot-iron. This term still survives in metallurgical literature, but in the German works where the metal is made, it is called *steel,* and the plant itself is called a *stahl werke* (steel works), so that we have the peculiar anomaly of a steel works making what is called steel by the workmen, while the official reports declare that it makes no steel at all. It seems inevitable that Germany must soon give up this outgrown system.

The current usage in our country and in England in regard to wrought-iron and steel may be summarized in the following definitions:

(1) By the term wrought-iron is meant the product of the puddling furnace or the sinking fire.

(2) By the term steel is meant the product of the cementation process, or the malleable compounds of iron made in the crucible, the converter or the open-hearth furnace.

THE MAKING OF CRUCIBLE STEEL.

Most of the hard steel in the market to-day is made in the open-hearth furnace. Enormous quantities are used for car springs and agricultural machinery, and both the acid and basic furnaces furnish a share. There are some purposes, however, which call for a steel entirely free from the minute imperfections often present in open-hearth metal. Such is the case in watch-springs, needles and razors; and it is found that the old crucible process gives in the long run the most satisfactory metal for such work.

This process consists in putting into a crucible a proper mixture of scrap, pig-iron, or charcoal and heating it until everything is thoroughly melted, the crucible being kept tightly closed to prevent the admittance of air. This process is a century old, but bids fair to round out another with little change.

THE ACID BESSEMER PROCESS.

The Bessemer process consists in blowing cold air through liquid

pig-iron. Sometimes the pig-iron is brought directly from the blast-furnace while fluid, and sometimes it is remelted in cupolas. In the early plants in England and America the lining of the vessel which held the iron was of ordinary silicious rock and clay, and this is still the universal practice in America. In other countries it has been necessary to develop a modification of the process, the linings being made of basic material, whereby the chemistry of the operation is greatly changed.

The growth of the basic Bessemer practice made it necessary to have a distinguishing name for the old way, and it is therefore called the *acid* process, the word being used in a chemical sense rather difficult to explain to any one not versed in chemistry.

In the acid process, the air passing through the iron burns the silicon and carbon, while the heat caused by their combustion furnishes sufficient heat to not only sustain the bath in a liquid state, but to increase its temperature, and to oftentimes necessitate the addition of scrap or steam as a cooling agent.

This increase in temperature is due principally to the silicon, which is of great calorific power, while the burning of the carbon gives barely sufficient heat for the bath to hold its own. It is necessary, therefore, that the iron contain sufficient silicon to raise the temperature to the point where steel will remain perfectly fluid. In the old days when operations in a steel works were slow and converters were allowed to cool off between charges, it was necessary for the pig-iron to have about 2 per cent. of silicon to get sufficient heat, but with the rapid methods of to-day, it is found that 1 per cent. is enough.

When the silicon and carbon are all burned, a certain amount of manganese is added in order that the steel shall be tough while hot, and be able to stand the distortions it is subjected to in the rolling mills. If soft steel is wanted, this manganese is obtained by using a rich alloy called ferromanganese, containing 80 per cent. of manganese, while if rail steel is being made, the usual method is to make a liquid addition of spiegel iron—a pig-iron containing about 12 per cent. of manganese.

For every ten tons of steel about one ton of this spiegel will be added, and this at the same time gives enough manganese to make it roll well, and enough carbon to confer the necessary hardness. When the rich alloy is used to make soft steel, as before explained,

the amount added is very small and the carbon thus carried into the bath is trifling.

The resulting steel is poured into a ladle, and the slag, being very light, floats on the top. The steel is then tapped from the bottom, the separation of metal and slag being perfect. Minute cavities of slag are often found in steel, but these come from internal chemical reactions, or sometimes from dirt in the mold. They do not arise from mixture of the metal and slag when poured in the way that is almost universally used in Bessemer and open-hearth works.

In this acid process there can be no removal of phosphorus or sulphur, and as no steel is allowed to contain over one-tenth of one per cent. of either, it is plain that the pig-iron must not contain more than this allowable amount. It has been shown, in the discussion of the manufacture of pig-iron, that the phosphorus in the ore will appear in the metal. Consequently if the ores of any district contain more than one-twentieth of one per cent. of phosphorus, which will give one-tenth of one per cent. in the iron, that district cannot possibly use the acid Bessemer process. If they do contain as little as this, then this process is the cheapest method of making steel that has ever been discovered or probably ever will be.

THE BASIC BESSEMER PROCESS.

The basic Bessemer process is similar to the acid Bessemer, both being founded upon the general truth that if cold air be blown through pig-iron, the combustion of the impurities in the iron will furnish sufficient heat to keep the metal in a fluid state. In the acid process it has been shown that only two elements are thus burned, viz., silicon and carbon, and that the silicon supplies most of the heat.

In the basic process the lining is made of basic material, usually of hard burned dolomite, which is a limestone containing from 30 to 40 per cent. of magnesia. When the linings are basic, it is a bad thing to have much silicon in the iron, because when silicon is oxidized it forms silica (SiO_2), and this attacks the lime lining. The percentage of silicon is therefore kept as low as possible, and this makes it necessary that some other source of heat be provided. This is the more necessary because more heat is needed in the basic process than in the acid, on account of the lime which is added in the converter and which must be melted during the operation.

The element used to take the place of silicon and supply heat is

phosphorus. In the acid process phosphorus is not eliminated at all, but when the linings are basic it is possible to add lime and make a basic slag in which phosphorus can exist as phosphate of lime or phosphate of iron. In the acid process it is not feasible to add lime, because the lining of the converter would be eaten away and the slag could not remain basic enough to hold the phosphorus.

As already stated, the basic Bessemer process requires more heat than the acid process, because considerable lime must be added to give a basic slag, and because the lining of the vessel is eaten away much faster. It has also been explained that silicon is not allowed in the iron to any extent, because the more silicon there is present, the more lime must be added to counteract it.

Inasmuch as silicon is the principal source of heat in the acid process, and as still more heat is required in the basic converter where silicon is not allowed, it is evident that phosphorus, which replaces silicon as a heat-producing agent, must be present in considerable quantity. In the basic Bessemer works of Germany the iron contains about 2 per cent. of this element. If it falls much below this, the heat produced is not sufficient to give the proper temperature to the fluid metal at the end of the blow. In English practice it is considered necessary to have a higher proportion.

Thus it happens that the Bessemer process is applicable to only two kinds of ores:

(1) Those containing only a trace of phosphorus, giving an iron suitable for the acid process.

(2) Those containing a high percentage giving an iron containing 2 per cent. of phosphorus, suitable for the basic process.

There are many deposits of ore in different parts of the world which are intermediate between these classes, and which give a pig-iron ranging from one-tenth of one per cent. up to one and one-half per cent. These irons are not suitable for either form of the Bessemer process, although it often happens that an iron which contains too little phosphorus for the basic vessel can be used in admixture with an iron that contains a surplus. When this is impracticable, such irons can be used for steel only in the basic open-hearth furnace.

When the air is blown through the melted iron in a basic converter the silicon is first oxidized, and the carbon next. Thus far the operation is the same in both the acid and the basic vessel.

At that point the acid process ceases, but in the basic process the blast of air is continued and the phosphorus is oxidized and passes into the slag. The slag therefore contains a considerable percentage of phosphorus and this makes it valuable as a fertilizer. The demand for it is unlimited and the revenue derived from it is a very important matter to all plants using this process. The cost of labor, however, and the greater waste and diminished output of a basic Bessemer render this process out of the question except where suitable pig-iron can be had at a much lower price than iron fit for the acid process. In the United States this condition does not exist and there is no plant in operation in this country.

The final operation of adding spiegel iron or ferromanganese is conducted in practically the same way in the basic Bessemer vessel, as has already been described in the account of the acid process.

THE OPEN-HEARTH FURNACE.

An open-hearth furnace really means a furnace having a hearth exposed to the flame, so that any piece of steel or other material placed upon the hearth is exposed openly to the action of the burning gases. The term has been narrowed by custom to denote such a furnace where steel is melted. A furnace for this purpose must be regenerative in order to get the requisite intense temperature. Regenerative furnaces are also used very generally for heating steel in rolling mills, but they are not called open-hearth furnaces except when the steel is actually melted.

By a regenerative furnace is meant one in which the heat carried away in the stack gases is used to warm the air and gas before they enter the furnace. Strictly speaking, a furnace would be regenerative if air pipes were put into the stack and the air blast were passed through these pipes. But by custom the term means only a furnace which is heated by gas, and where both gas and air are heated before they enter the furnace by being passed through chambers filled with bricks loosely laid, these bricks having previously been heated by the waste gases. By having two sets of chambers, one set can be used to absorb the heat in the waste products and the other set to warm the incoming gases. By proper systems of reversing valves these two sets of chambers can be used alternately for each purpose, and in this way the gas and air are heated to a yellow heat before they unite, and it is quite evident that yellow-hot air and yellow-hot gas will give a very intense heat.

The problem in an open-hearth melting furnace is not to *reach* the desired temperature, but to *control* the temperature and prevent the roof and walls from melting down.

THE ACID OPEN-HEARTH PROCESS.

The term acid open-hearth furnace means a regenerative gas furnace used for melting steel, and lined with silicious material (sand). It has been shown that the Bessemer process can be conducted in a vessel lined with silicious material, or in a vessel lined with basic material, and it has been shown that this difference in lining makes a radical difference in the process. In the same way the manner in which a steel melting furnace is lined profoundly influences the subsequent operations. Contrary to popular belief, the bottom in itself plays very little part and has very little influence, but the character of the bottom determines the character of the slag that can be carried, and the character of the slag determines the chemistry of the process.

In the acid open-hearth process a mixture of pig-iron and scrap is charged into the furnace and melted. Nothing is added to form a slag, as the combustion of the silicon and manganese, together with some iron that is oxidized, and some sand from the bottom, affords a sufficient supply. The slag is about half silica (SiO_2), while the other half is composed of oxides of iron and manganese. When the mass is melted it is fed with iron ore, and the oxygen in the ore oxidizes the excess of carbon until the required composition is attained, whereupon the steel is tapped, the proper additions of manganese being made at the time of tapping. Melted spiegel iron, so generally used in Bessemer practice, is not used in open-hearth work, but the manganese is added in the form of a rich ferromanganese, which is generally thrown into the ladle as the heat is tapped. Sometimes a spiegel iron is used, but this is put into the furnace a little while before tapping and allowed to melt.

It is necessary for the highest success of the operation that the slag should be kept within certain limits in regard to its chemical composition, for if it contains too much silica it is thick and gummy, and the operation will be much retarded, while if it contains too much oxide of iron it will be sloppy and the metal will be frothy and over-oxidized. It would seem at first sight that there would be considerable difficulty in regulating the composition of a slag that is constantly receiving iron ore and constantly absorbing

silica from the bottom. Moreover, the amount of ore is not constant nor the rate at which it is added, for on some heats scarcely any ore is thrown in, on others there may be 500 pounds added in three or four hours, and on others there may be 3,000 pounds used in the same period of time.

As a matter of fact, there is very little difficulty in maintaining a very regular chemical composition if moderate judgment be exercised and the additions of ore are regulated by the temperature of the furnace and the condition of the metal. Many an open-hearth melter has never heard of silica, and yet can keep a constant percentage of it in his slag. This is due to the fact that the slag regulates itself to a great extent. The pig-iron used in the charge always contains silicon and this furnishes silica. If the amount is not sufficient, there will be a cutting away of the sand bottom to supply more. We thus have by the wearing of the bottom an inexhaustible source of supply of silica. In the same way we have a similar supply of iron oxide by the oxidation of the iron of the bath. If iron ore is added, this is the easiest way for the slag to get the oxide, since it simply appropriates it to its own use. Iron ore is a compound of two atoms of iron with three atoms of oxygen, expressed in chemistry thus—Fe_2O_3—,wherein Fe is iron and O is oxygen, and the figures represent the proportions. If the slag contains too high a percentage of silica, and needs more iron oxide, and if under these conditions iron ore is added, then only one of these atoms of oxygen goes toward oxidizing the silicon and carbon of the bath. This leaves two atoms of iron and two atoms of oxygen, and these unite together to form two parts of a different oxide, FeO, or since there are two atoms of each, thus—2FeO.

The extra atom of oxygen has united with carbon and formed a gas in which one atom of carbon unites with one atom of oxygen. In chemistry this action is expressed thus: C+O=CO. The symbol C stands for carbon, and O for oxygen, and when united in equal proportions, they form CO, which is the chemical symbol for carbonic oxide.

The whole operation of adding iron ore to an open-hearth bath, when only the extra atom of oxygen is given to the carbon, and the rest of the oxide stays with the slag, may be expressed by the following simple chemical formula:

$$Fe_2O_3+C=2FeO+CO.$$

This concentrates in one line all the explanation we have just gone through.

Sometimes the slag has a sufficient supply of oxide of iron and needs no more. In this case, when ore is added, all the oxygen goes to the carbon of the bath so that there are three atoms of oxygen calling for three atoms of carbon. This leaves the iron alone in its metallic state and it is instantly dissolved in the bath, and the weight of the charge is increased by just so much. The chemical symbol expressing this is as follows:

$$Fe_2O_3+3C=2Fe+3CO.$$

Generally it will happen that the truth lies between these two conditions; that the slag keeps part of the oxide and the rest is reduced, part of the oxygen uniting with carbon and part of the iron being dissolved in the bath, the remainder of the oxide of iron entering the slag.

Still another condition exists whenever iron ore is not added to the bath. Under this state of affairs, it may be necessary for the slag to have more oxide of iron, and there is no place for this to come from except the bath. Therefore, when there is need of oxide of iron, the iron of the bath unites with the oxygen of the flame and goes into the slag.

Thus it is clear that if no iron ore is used, a certain equivalent amount of good stock must be oxidized, and that if iron ore is used the weight of metal tapped will be greater than if it had not been added.

The amount of carbon in the steel, and therefore the tensile strength, depends entirely on the conduct of the operation, but the amounts of phosphorus and sulphur depend upon the kind of stock which is put into the furnace. If a superior quality of steel is required the original stock should contain only small percentages of these elements. Such stock, however, costs more money than common scrap. If an ordinary quality is required then ordinary pig-iron and scrap are used.

It is a common belief that it is an easy thing to distinguish between open-hearth steel and Bessemer steel. It is usually very easy to tell basic open-hearth steel from acid Bessemer, or acid open-hearth from basic Bessemer, but it is impossible by any ordinary means to tell acid Bessemer from acid open-hearth or basic Bessemer from basic open-hearth. Most American metallurgists

and engineers, however, agree that open-hearth steel of a given composition is more reliable, more uniform, and less liable to break in service than Bessemer steel of the same composition. And there are many metallurgists and engineers both in this country and abroad who believe that acid open-hearth steel is more reliable than basic open-hearth steel of similar composition. In Chapter XVII it will be shown that there is mathematical evidence to support this opinion.

A fact bearing upon this question is that in Germany there are two companies which make a business of special steel for forgings, tools, etc., etc. These companies use acid Bessemer steel for this work, although basic steel is cheaper. They are the only makers of acid steel in the great Ruhr district, and the basic Bessemer works do not invade their lines of business. This would indicate a belief in the superiority of the acid product.

THE BASIC OPEN-HEARTH PROCESS.

The term basic open-hearth furnace means a regenerative gas furnace, used for melting steel and lined with basic material, usually either magnesite or burned dolomite.

It has been stated in discussing the acid open-hearth that the bottom itself takes very little part in the operation, but that it determines the character of the slag that can be carried. When the bottom of the furnace is made of silica (sand) the slag must be silicious; but when the bottom is basic the slag must be basic. Consequently in the basic open-hearth furnace the charge is composed of pig-iron and scrap, just as in the acid furnace, but, in addition to this, a certain amount of lime or limestone is added. The whole mass of iron, scrap and lime is melted down by the action of the flame. The silicon and carbon of the pig-iron are oxidized, just as in the acid process; the manganese of the scrap and some of the iron are both oxidized just as on the sand bottom; but the silica and the oxides of iron and manganese do not make a slag by themselves, for they unite with the lime that has been added. This gives a basic slag, and when the slag is basic the phosphorus in the pig-iron and scrap will be oxidized and enter the slag as phosphate of lime or iron, just as it does in the basic Bessemer vessel. Thus the basic open-hearth furnace will allow the purification of iron con-

taining phosphorus, and for the same reason, but in very much less measure, sulphur can be eliminated.

After the charge of pig-iron and scrap is melted, iron ore is added as fast as necessary to oxidize the excess of carbon, and when the metal has reached the desired composition it is tapped into the ladle, the additions of manganese being made in the same manner as in the acid furnace.

The principles underlying the reactions in a basic furnace may briefly and incompletely be stated as follows:

(1) Silicon oxidizes readily at a high heat under almost all conditions. Its oxide is sand (SiO_2), which acts as an acid, by which is meant that it will combine if it has a chance with one of the bases or earths, like lime, iron or manganese.

(2) Phosphorus oxidizes readily, but it will not stay in the form of oxide unless the conditions are favorable. Its oxide is phosphoric anhydride (P_2O_5), which acts as an acid like silica; but silica when formed is stable and will stay where it is put, but the oxide of phosphorus must have something to unite with, and this something must be one of the bases or earths like lime, iron or manganese. If oxide of phosphorus is formed and there is no base for it to unite with, the metallic iron robs it of its oxygen, and then we have oxide of iron, while the phosphorus is left alone, dissolved in the bath.

(3) The oxide of phosphorus requires a considerable quantity of bases to unite with. If the quantity is limited, the phosphorus may stay for a time, but will then leave. If a slag contains all the phosphorus it can hold at a certain temperature and the furnace gets hotter, some of the phosphorus will go back into the metal. If, with the same slag the carbon begins to burn faster from any cause, the phosphorus will go back into the metal on account of the reducing action being stronger.

(4) The oxide of phosphorus does not hold on with equal force to all bases. If it is combined with lime it is much harder to pull it back than if it is combined with iron.

(5) Since oxide of phosphorus acts as an acid and combines with a base, it is evident that a slag which is absorbing phosphorus becomes every moment more acid, and thus becomes every moment less capable of further absorption.

(6) It is the rule in slags that a mixture of several different acids and bases will be more active than a slag made of one acid

and one base. Such a complex slag, all other things being equal, will be more fluid in the furnace than a simple slag.

(7) In all furnaces, whether acid or basic, there is more or less of an automatic regulation. In the acid furnace the percentage of silica will be constant, for if there is not enough silicon in the charge to supply the necessary silica, the slag will eat away the bottom until it is satisfied. The total content of the oxides of iron and manganese will be constant, for if there is no ore added, the iron of the bath will be oxidized. If ore is added, the silicon and carbon of the bath unite with the oxygen of the ore and the iron goes into the bath. Thus the slag takes care of itself on an acid hearth.

(8) In the basic furnace the slag takes care of itself to some extent, but the cutting away of the hearth must not be allowed, and if phosphorus is to be eliminated, a sufficient quantity of lime must be added. Given the right amount of lime, there is then a considerable self-adjustment of the slag by the oxidation of the iron of the bath or by the reduction of the iron from the slag. If much lime be added, it will tend to drive the iron back into the bath, although it can never do it completely, while if little lime be added, there will be a greater proportion of iron in the slag.

(9) It is necessary that the slag shall be so basic that it will not attack the bottom. If it is so, it is basic enough to hold all the phosphorus that will be present if the stock contained only a moderate amount—say not over one-half of one per cent. If the stock contained far in excess of this, as often happens, special attention must be paid that phosphorus does not pass back into the steel when a high temperature is combined with violent agitation and perhaps a reducing action, these conditions being often present when the heat is tapped.

SEGREGATION.

Every engineer knows that steel is not homogeneous. Manufacturers have always known it, but they have usually said very little about it. It is a much safer plan to state the facts and let proper allowance be made in the proper place. The tendency among structural engineers is continually toward heavier work. The size of beams and angles and girders is greater now than it was some years ago, and the percentage of the heavy sections is greater. These heavy pieces necessarily mean heavy ingots in

order that there shall be sufficient work upon the steel to give it a proper physical structure, and these heavy ingots mean a larger cross-section, and this means that it takes a longer time for the ingot to cool from the liquid to the solid state.

During all the time the ingot is liquid there is a process going on by which the carbon, the phosphorus, and the sulphur are becoming concentrated in the central portion of the mass and rising to the upper portion. During the operation of rolling and shearing off the ends, the worst of the ingot is discarded, but the central portion of what is left is not uniform with the outside portions. It is evident that in most sections this impure portion will constitute the neutral axis, and thus its influence be reduced to a minimum. In certain cases, however, as in armor plate and ordnance, great care is taken to reject all contaminated portions. This could be done in structural material, but it would involve much expense, and no engineer would be justified in insisting upon such a course, since contracts are founded upon ordinary commercial practice, and this ordinary practice allows a certain measure of segregation to exist. Specifications are sometimes written in which explicit directions are given that in tests cut from the finished material an increase will be permitted in the allowable content of impurities. This is simply stating clearly what has long been a recognized fact.

Perhaps the most troublesome instances of segregation occur in plates rolled directly from ingots. It usually happens that the top surface of the ingot is solid and that a cavity exists beneath. When this is rolled into a plate, it is possible to shear the plate so that this inner cavity is not opened, and we then have a finished plate which has an area of lamination and an area of segregation, and these are not in the center of the plate, but near one edge. The test pieces are almost always taken from the corners, so that they never reach the segregated portion, and there is nothing to mark the dangerous condition of the plate. In plates rolled from slabs there is often a streak of segregation running through the central axis, but there is not the centralization of impurities that occurs in the older method of manufacture.

THE INFLUENCE OF HOT WORKING UPON STEEL.

When an ingot of steel is cast in a mold and allowed to cool it is not a homogeneous mass of uniform strength throughout. Its

structure is coarsely crystalline and these crystals do not always have a firm hold on each other. Moreover, there are many small cavities, called blowholes, distributed unevenly but mainly very near the surface, and oftentimes a much larger cavity in the center of the upper portion. There are also shrinkage cracks extending inward from the surface, these cracks being very numerous in the case of steel that is poured at a very high temperature.

When the ingot is heated and rolled all these disturbing factors tend to disappear. The crystals are forced together and come into more intimate contact; the blowholes are crushed out of existence, and although their sides are not always perfectly welded together they at the worst become mere lengthwise seams, which have no influence on the longitudinal strength and scarcely any on the bending or torsional stiffness; the central cavity is cut off when the top is cropped at the hot shears; the cracks are at first opened up by the rolls and are then either worked out into a perfect surface or show themselves in open and staring flaws that condemn the bar and so prevent its use in structural work.

It will be evident that the more work that is put upon the piece the greater will be the tendency to remove flaws and to secure homogeneity. Of course, if an ingot is not alike at the top and bottom no amount of work will make the bar from the upper end like the bar from the lower end, but the effect of the continual working in the rolls will be toward doing away with local irregularities in both physical and chemical condition. For these reasons and particularly on account of the elimination of surface imperfections, the tendency of modern rolling-mill practice is toward the use of larger ingots. In cases where the ingot is rolled into the finished bar at one heat it will be evident that with a large ingot the bar will be finished at a lower temperature on account of the greater time necessary to do more work, and this lower finishing temperature is beneficial. In cases where the ingot is not finished at one heat the use of a large ingot renders it possible to get a clean bloom of large size, and this again makes it probable that the bar will be finished at a low temperature.

THE EFFECT CAUSED BY CHANGES IN THE SHAPE OF THE TEST PIECE.

It is the custom for engineers to specify that steel shall give a certain percentage of elongation, but it is seldom that anything is

said as to how and where the test shall be taken. This omission is covered by a general understanding in the trade so that there is seldom any trouble in the case of standard structural shapes. Wherever it is possible the test piece is taken so as to leave two parallel rolled surfaces on the test bar, the other two sides being machined. This can readily be done with plates, beams, channels, angles and similar shapes. In small rounds the whole piece is taken as it comes from the rolls. In the case of plates it is understood that the test piece is to be taken lengthwise of the plate unless stated otherwise in the specifications. In forgings, however, no absolute standard can be given, but it is usual to cut a test from a prolongation of the piece at a short distance below the surface. In many cases this is unnecessary, and it will suffice to forge a small bar from the heat and finish this either at a small hammer or at a rolling-mill. In other cases, like armor plate and cannon, stringent provisions are incorporated in the specifications.

The results obtained from test pieces of different shape are not the same. The general section, whether round or rectangular, makes a difference, and in a rectangular piece the relation of the width to the thickness influences the result. It will be seen that this latter fact is important in cutting strips from angles or flats of varying thickness. Needless to say that the length is the one predominant factor. Just before breaking there is a drawing out of the bar in the immediate neighborhood of the place where it is going to break, and this local stretch will be a greater proportion of the total in the case of a bar two inches long than with a bar ten inches long. In order that records shall be comparative, the length of eight inches is used throughout England and America, except for forgings and castings, in which cases a 2-inch test is often used, as it is both inconvenient and expensive to get the longer piece. In foreign countries the standard length is 200 millimeters =7.87 inches, so that the results are fairly comparable with our 8-inch test.

The general laws may be thus summarized, the data from which the conclusions are drawn being given in Chapter XVI.

(1) A rolled round will give the best results if tested in the shape in which it leaves the rolls. If the outside surface is removed by machining the elongation will be reduced.

(2) The tensile strength of a plate as determined by the grooved (marine) section will be from 6500 pounds to 12,500

pounds per square inch higher than if determined by the parallel-sided test.

(3) Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation, and a slightly lower reduction of area.

(4) In testing flats the elongation increases regularly as the width increases, while the reduction of area regularly decreases.

(5) The percentage of elongation decreases as the length of the test piece increases. The law of change is such that if a piece 8 inches long gives 30 per cent. elongation, a piece of infinite length would give about 24 per cent.

THE INFLUENCE OF CERTAIN ELEMENTS UPON STEEL.

Nothing is more difficult than to state accurately the effect of different elements upon the strength and ductility of steel. Those who have studied and worked over the problem differ among themselves and differ widely. Yet it is a common thing for engineers to write a specification calling for a steel of a certain tensile strength, and limiting the content of carbon, phosphorus, manganese and sulphur. It often happens that such specifications are impracticable, if not impossible. For instance, the tensile strength is allowed to vary between 60,000 pounds and 70,000 pounds per square inch, but it may be that the highest allowable contents of carbon, phosphorus and manganese will actually give a strength of only 65,000 pounds. Now it will be evident that the true allowance of tensile strength is not 10,000 pounds, but 5000 pounds. It is also evident that the manufacturer must keep his phosphorus and manganese at the highest point, a thing the engineer is very far from wishing, but which he has ignorantly made necessary.

The slightest consideration will show that it is a mathematical impossibility for the engineer to put both chemical and physical limits and have them coincide, unless he knows absolutely the effect of each element upon the strength of steel, and no man in the world claims to know that to-day. It is right for the engineer to specify certain parts of the chemical formula, but he must leave room for the manufacturer to attain the physical results. If he specifies the phosphorus limit, he should leave the carbon open, and if he specifies the carbon he should leave the phosphorus and manganese to the manufacturer.

Following are the elements usually found in steel and the general influence they have upon the physical properties. In each case the statements are my own opinions. In a general way they will be agreed to by almost all metallurgists, as far as structural steel is concerned.

Silicon: This element is seldom present in structural steel in quantities greater than a trace, and the effect of these minute quantities may be ignored. It is present in steel castings in amounts up to four-tenths of one per cent., but its influence is not great for better or for worse.

Copper: This element has some influence on the hot properties, but not as much as generally supposed, as its effect is often masked by sulphur, with which it is generally associated. It has no effect on the cold properties as far as known.

Manganese: The most important function of this element is to give ductility while the steel is hot, so that the piece can be rolled into finished form without tearing. Ordinary structural steels contain from .30 to .60 per cent. and within these limits it has very little influence upon either the tensile strength or the ductility. Above this amount it adds to the tensile strength, but does not materially decrease the ductility. It would seem, however, to slightly increase its liability to break under shock, although this is not proven.

Sulphur: This element has just the opposite effect from manganese and makes the steel crack while it is being hot rolled. After the metal is cold it seems to have no appreciable effect upon the physical properties.

Phosphorus: This element has little effect upon the hot properties, but in the cold state it makes the steel brittle and adds to the tensile strength in about the same degree as carbon. In other words an increase of one-hundredth of one per cent. (.01 per cent.) of phosphorus increases the tensile strength about one thousand pounds per square inch. In ordinary steels the phosphorus is always limited to one-tenth of one per cent. In special steels much lower limits are given.

Carbon: This is the one element used above all others by manufacturers in getting required physical properties. An increase of one-hundredth of one per cent. (.01 per cent.) gives an increase in tensile strength of about 1000 pounds per square inch. It decreases the ductility slightly and regularly. When steel is heated

red hot and plunged in water the carbon in the metal unites with the iron in some peculiar way so as to produce a compound of extreme hardness. If the steel contain one-third of one per cent. of carbon a sharp point so quenched will scratch glass. With two-thirds of one per cent. the steel is hard enough to make common cutting tools. With one per cent. it reaches nearly its limit of hardness. This percentage is used for the harder tools, but with higher carbons the brittleness increases so fast that the usefulness of the metal is limited.

Nickel: This element in alloy with steel gives a metal with a high elastic limit and having great toughness under shock. Its principal uses are for armor plate and special forgings.

Chapter XVII describes two investigations I have made into the influence of the metalloids. The first was by the Method of Least Squares and the second by plotting. The formulæ deduced were as follows:

First Method:

A. Acid Steel 38600+1210C+890P+R=Ultimate Strength.

B. Basic Steel 37430+950C+85Mn+1050P+R=Ultimate Strength.

Second Method:

C. Acid Steel 40000+1000C+1000P+XMn+R=Ultimate Strength.

D. Basic Steel 41500+770C+1000P+YMn+R=Ultimate Strength.

In equations C and D the factors X and Y are variables, being zero in a low steel, but rising with each addition of carbon and manganese.

In these equations the contents of carbon, manganese and phosphorus are to be given in units of .01 per cent., while R is a factor depending upon the finishing temperature, and it may be plus or minus. The results indicate that the metalloids have different quantitative effects upon acid and basic steels. Now, if acid steel does not follow the same law as basic steel, then they are not the same, and if they are not the same, then it is possible that one is better than the other, a possibility that is vigorously denied by some people.

I find that it takes more carbon to give a certain tensile strength in basic than in acid steel, even when the phosphorus is the same, and this is a bad thing because every increase in carbon gives a better chance for segregation and lack of uniformity. I do not say that this in itself proves basic steel to be unreliable, but it does indicate that acid steel may be preferable in some cases.

SPECIFICATIONS ON STRUCTURAL MATERIAL.

It is the custom for engineers to specify the kind of steel they wish, and what the physical requirements shall be. It sometimes happens that the engineer does not understand all about the different kinds of steel and does not know what elongation and reduction of area should be obtained in each case. He often takes the first specification he finds and adds to it some special idea which has been impressed upon his mind. There are many such specifications used by engineers. Some of them are out of date, but hold their place because the longer they have been in use the more reverence they receive from certain people, and the more proud of his work is the author. His name attached to a set of specifications is a constant advertisement, and arouses a pardonable feeling of self-satisfaction. These conditions, however, do not serve scientific progress.

In 1895 the Association of American Steel Manufacturers adopted a set of specifications, and although it was claimed that it was not the place of the manufacturers to do this, yet the users of structural material eagerly grasped these specifications as filling a long-felt want, and they are the basis of business to-day. There are two facts which may well be kept in mind:

First: The steel manufacturers in session assembled may be supposed to know something about steel.

Second: It is not for their interest to advocate a bad material. It might be for the interest of one of them to pass a bad lot of steel on a single contract, but as a whole they have no incentive to plead the cause of something they think is bad.

The steel makers are not a unit in all matters, but they agree in some things. Most of them believe that Bessemer steel will do for buildings, highway bridges and similar purposes. They believe that open-hearth steel should be used for railway bridges, for boilers, for locomotive forgings and other purposes where the steel

is subject to vibration and shock, and that in such open-hearth steel the phosphorus should be lower than in the ordinary run of Bessemer steel. In some other matters they do not agree. They differ in regard to acid and basic steel. It is my opinion that acid steel, other things being equal, is superior to basic steel, but the manufacturers, being unable to give an authoritative opinion, leave the matter open to the engineer, stating what the phosphorus shall be in each case. This whole subject of specifications is now under consideration by the engineering societies of our country and especially by the American Society for Testing Materials. No ordinary specification, however, can take account of all the variations in the physical results from bars of different section, but certain laws must be recognized by the engineer and the manufacturer. These laws may be stated as follows:

(1) In rounds an increase in diameter is accompanied by a decrease in ultimate strength, a greater decrease in elastic limit, an increase in the elongation, and a decrease in the reduction of area.

(2) In angles an increase in thickness is accompanied by a decrease in ultimate strength, a greater decrease in the elastic limit, and a decrease in the reduction of area, while the elongation remains constant.

(3) In plates a thickness of $\frac{3}{8}$ inch to $\frac{1}{2}$ inch should be taken as the basis.

Thinner plates will show higher tensile strength, much higher elastic limit, lower elongation and lower reduction of area.

Thicker plates will show lower ultimate strength, much lower elastic limit, lower elongation and lower reduction of area.

Narrow plates will give higher elongation and higher reduction of area than wide plates.

Tests cut crosswise of the steel will usually show lower ultimate strength, lower elastic limit, lower elongation and lower reduction of area. This is most marked in long, narrow plates.

Universal mill plates will show a greater difference between lengthwise and crosswise tests than will be found in sheared plates.

(4) In channels, beams and similar sections, the tests cut from the web will follow the laws just stated for plates of medium width. In pieces cut from the flanges there will be a lower ultimate strength, a lower elastic limit, and a lower reduction of area.

(5) In eye-bars, an increase in thickness will show a lower ulti-

mate strength and a much lower elastic limit. The elongation will decrease as the length increases, so that if a length of 15 feet gives a stretch of 15 per cent. a length of 35 feet will not give over 13 per cent.

WELDING.

In the days of wrought-iron, welding was the basis of all forging and of very much structural work. To-day all structural members are of steel, as well as a great proportion of the stock in the shop of the village blacksmith. This soft steel will weld, and the average blacksmith and machinist, to say nothing of some engineers who ought to know better, believe that a welded piece of steel is practically as good as a new bar. As a matter of fact, while a weld is better than nothing, and while it may have half the strength of the natural bar, and may have its full strength, it does not have its toughness and is unfit to use where failure will be dangerous, and where it can be avoided. It is also true that a weld of wrought-iron is entirely unreliable.

STEEL CASTINGS.

A steel casting is a mass of steel poured directly into finished shape from fluid steel made in the regular way. In this country acid open-hearth furnaces are generally used, but in Germany the basic furnace is often employed. Sometimes the Bessemer converter is used for this work. One of the latest forms is known as the Tropenas process. Instead of having the tuyeres in the bottom of the converter, the air is blown at a low pressure upon the surface of the bath. At a point from four to seven inches above this set of tuyeres is another set, which supplies air to burn the carbonic oxide coming from the metal. This upper row of tuyeres is not operated until the blowing is well under way. The lower tuyeres oxidize the carbon to carbonic oxide (CO), just as in an ordinary converter, while the upper tuyeres burn this to carbonic acid (CO_2). In this way there is a great increase in the amount of heat produced and the steel will be hotter than if blown in the usual way.

In the steel foundry, it is the practice to put "sink-heads" on steel castings. These are masses of metal that rise above the rest of the casting and are of such size that they stay liquid while the main body is solidifying, and the metal flows from these heads down

into the casting to supply the gap made by shrinkage. These "sink-heads" or "risers" must be cut off by saws or otherwise, and it often happens that the surface so exposed shows a few holes. These holes do not indicate a bad casting, as the fault is purely local. On the other hand, it often happens that the casting is machined in one or more places, and this exposes minute blowholes. These usually are not serious, and, as a rule, the holes do no harm in themselves, as the strength of the casting is just the same as if an equal number of holes had been bored with a tool.

A casting of complicated shape is likely to be internally strained by the cooling of the mass. Certain parts will be in tension and certain parts in compression. In simple shapes these conditions do not exist to any extent, but in complicated forms it is well to anneal the whole casting. This process when properly conducted changes the crystalline structure and increases its ductility. The improvements invented in the last few years in the way of pyrometers allow this process to be carried out with scientific precision, instead of in the old haphazard method that often did as much harm as good.

INSPECTION.

Nothing is easier than to write the self-evident laws that should govern the inspection of steel, for the manufacturer should supply what is required and the inspector should receive nothing else. If the steel does not fulfil the specifications, it is the fault of the maker, and all the chances and losses of error should have been taken into consideration in making the contract. Moreover, the inspector is only an agent, and he violates his trust in accepting anything that falls outside the limits which, either wisely or foolishly, have been set by his principal.

These facts are patent; but trouble does arise, and it will be to the advantage of all concerned if the points of difference are discussed. The main causes of disagreement are as follows:

(1) Dishonesty of the manufacturers.

(2) Open disregard of specifications by the manufacturers.

(3) Bad construction of the specifications.

(4) Conscientiousness and non-discretionary powers of the inspector.

The dishonesty of the manufacturer is a sad fact which occa-

sionally appears in evidence, but where one instance becomes known a dozen escape observation, for cheating is so easy, even with careful supervision, that the temptation is hard to overcome when large financial stakes are put in hazard by absurd restrictions. It is a physical impossibility for any ten men to follow the material through the processes of manufacture to see that no false marking is done, and although it is true that the buyer has the privilege of investigating the steel at a subsequent time, every one knows that engineers do not go into the erecting shops and cut pieces out of the angles, and test and analyze the samples. Moreover, a dozen random tests would not show that some pieces were not wrongly marked, or that some of the metal was not outside of the specifications. It must also be considered that no ordinary tests can distinguish between Bessemer and open-hearth steel, or between acid and basic steel, while it is only the laboratory which can find whether the phosphorus is high or low. Inspectors should make reports based on their own knowledge; they should know how the steel is made, and, when fraud is suspected, should pick out the bars from which the tests are to be cut, see that no substitution is allowed, take drillings to responsible chemists, and endeavor to stop the deceptions which place the honest manufacturer at a disadvantage, as well as nullify the calculations of the engineer. In so doing it is necessary to enforce the spirit rather than the letter of the law. In order to reduce the friction to a minimum, the inspector should be clothed with discretionary power, for chemists will differ, and steel will not be absolutely uniform, and different rolled sections will give different results.

Some engineers require that inspectors shall watch every detail of manufacture by night and day. This provision may be necessary in some cases, but it is sometimes very unjust. A contract is often divided among two or more works, and it may happen that one of these succeeds in overcoming certain difficulties by ingenuity and study. Such an advantage is the rightful property of the originator, and the works making the discovery is entitled to all the gain that may result therefrom. Under this inquisitory system it is impossible to keep secret any detail of manipulation, since the inspectors, who travel from one works to another, will naturally carry such information to unsuccessful manufacturers. This may be done from the most commendable motives, but the result is more pleasant to Utopian philosophers than to business rivals.

The disregard of specifications by the manufacturer often appears in substituting Bessemer metal for open-hearth, or basic steel in place of acid, and there are cases where such material has been accepted. Needless to say that by so doing the engineer places himself in an unfair relation to every works which made a bid on the better quality of material, and needless to say that such a transaction casts a shadow of doubt over every clause in future contracts.

Such a concession is an acknowledgment that the specifications were written in ignorance, and while such error should be recognized when it exists, it would also be well if carefully considered requirements were enforced. Often there are details which are the result of carelessness. In a large contract embracing a number of foundation bolts and similar forgings, part were of steel from 70,000 to 80,000 pounds tensile strength, while the rest were from 72,000 to 82,000. The cause of this absurdity was a change in management with a revision of the specifications, and while the requirements for a certain portion were allowed to remain unaltered, new regulations were made for the rest of the work. The divergence was an accident, and yet the inspector refused to accept steel running 71,500 pounds for one bolt, while for another he would accept 71,000 pounds.

Mistakes in specifications call for discretionary power on the part of the inspector, and such power is needed also to settle questions of detail arising in the manufacture. Thus, during the construction of a large train shed, a few angles were needed of a special section not on hand. The time to put in rolls to make them would have cost many times what the angles were worth, but it was necessary to make a hard fight for permission to use angles of the same section and the same analysis and character, but which were one-sixteenth inch thicker than called for. It is conceivable that in a war vessel, where every pound is figured upon, an inspector would refuse to accept anything beyond the limit, and in the building of a long-span bridge the weights of materials should be carefully watched; but that the same care is necessary, in the face of great expense, in a small-span train shed, is a conceit which could only arise from misguided honesty.

A more striking example occurred in the assembling of the angles and plates composing certain large members where it was necessary to use a few long, narrow pieces not over one-sixteenth of

an inch in thickness, as filling pieces between riveted work of one and one-half inches in thickness. Although this was simply a washer, and although any storehouse could supply suitable sheets of ordinary steel, the inspector required that the steel be made especially for the place, and the same in composition and physical characteristics as the angles and plates, although this necessitated the making of contracts with sheet mills and the delay of the erecting work. The honest business man wants a competent inspector who knows how to get what is called for; who may examine a turnbuckle with a magnifying glass, but pays less attention to an angle for a hand railing; who hammers a fire-box sheet, but is lenient with a gusset-plate.

The proper way would be to place the inspection in the hands of a competent man, with full authority to make concessions or extra tests during the progress of the work. Under any system, most of the work will probably be done by subordinates who are not qualified to decide all questions that may arise, but the chiefs of American inspection bureaus are capable of meeting all responsibility.

In former days surface inspection was the most important function of the inspector; to-day it is the least of his duties. In fact, it has become such a matter of form that there is a tendency toward its complete abolition. There is much to be said in favor of such a step, for if an imperfection is discovered in any piece of steel, no matter if it has passed a dozen inspectors, the defective member must be replaced. Granting this condition, it is better for the manufacturer to reject unsuitable bars at the mill than to have them thrown out at distant points, and it will be to his interest to inspect all material before shipment.

The mill inspection is so carefully done in well-conducted works that it is unusual for an outside inspector to reject bars, and it would be still more thoroughly performed if the manufacturer knew the responsibility rested with him alone. Where the material is to be passed upon by an outside inspector, the natural tendency is to let doubtful bars go by, since the responsibility of their acceptance is to rest upon other shoulders. These facts are so well known that some of the best engineers in the country do not make any surface inspection.

Whether this practice be generally accepted or not, it is eminently desirable that the inspection bureaus should arrange to examine the

material as fast as it is made, so that double handling of stock may be avoided. Such handling often costs more than the inspection bureau receives for its work, and it is certainly an equitable request that some action be taken to remedy this loss.

ERRORS IN CHEMICAL RECORDS.

In 1888 the chemical societies of the world investigated the methods of steel analysis. They first condemned the method of carbon determination in general use and then approved certain other methods. Following the plan mapped out and under a system of duplicate determinations, one chemist reported on one sample 0.45 per cent. of carbon, while another reported 0.50 per cent. On a second steel the results varied from .15 to .18 per cent. In the case of phosphorus the English chemists reported .078 per cent. on one sample and the Swedes .102 per cent.

In an investigation by Wahlberg,* comparing the work of four laboratories of high repute, different chemists found the carbon in one soft steel to be from .118 to .191 per cent.; in a slightly harder steel from .200 to .254 per cent.; in a still harder steel from .590 to .692 per cent., and in a spring steel from .880 to 1.060 per cent. In color work the higher steels varied as much as 23 points, while the difference between the results by color and by combustion were as much as .185 per cent. in the hard steels.

In 1904 an investigation was carried on by the Cambria Steel Co., Johnstown, Pa., by sending drillings to twenty-three American steel works laboratories. As was to be expected, there was a wide variation. Carbon ran from .50 to .60 per cent. by color and .52 to .59 in a few combustion determinations. Silicon varied from .078 to .095; phosphorus from .093 to .108; sulphur from .032 to .042; and manganese from .68 to .87 per cent. Omitting in the case of each of the elements the lowest two and the highest two determinations, so as to have only nineteen results out of twenty-three, the carbon varied from .53 to .59 per cent.; the silicon from .080 to .093; the phosphorus from .099 to .104; the sulphur from .037 to .041; and manganese from .68 to .77 per cent.

In spite of these facts, there are engineers who issue specifications giving an allowable range of only .10 per cent. of carbon, say from .55 to .65 per cent., and specifying at the same time an al-

* *Jour. I. & S. I.*, Vol. II, 1901.

lowable range of only 10,000 pounds in tensile strength. Omitting the errors in chemical work, such a specification implies the existence of a formula expressing accurately the effect of all the elements upon the tensile strength, notwithstanding that in this field there are still some things to learn.

PART II.

THE METALLURGY OF IRON AND STEEL.

CHAPTER I.

PRIMITIVE METHODS OF MAKING IRON.

Iron ore is natural iron rust. It is a combination of iron and oxygen, and if we take away the oxygen the iron is left alone. If a large heap of charcoal be set on fire and urged by a hand bellows, and if iron ore be added to the heap, the oxygen of the ore will combine with the charcoal, while the metallic iron will separate in pasty globules. The temperature of such fire will not be high enough to melt the iron; it will not even be high enough to cause the iron to absorb a considerable quantity of carbon and thereby become pig-iron, but it will be high enough to cause the pasty globules to stick or weld together. In this way for thousands of years iron was made all over the world. Here and there improvements were made by protecting and confining the fire by brick walls, either in a hole below the ground or in a furnace above the level, and sometimes large bellows were used, driven by water power, but the scale of working was always small. The Catalan forge, which was in use in more or less modified form in every country of the world, was nothing but a hole in the ground about two feet square and two feet deep. This was filled with charcoal and ore, sometimes carefully arranged in two vertical parallel layers, and sometimes mixed together; a blast of air inclined downward, the tuyere being pushed into the midst of the mass, completed the apparatus. In America this rude contrivance was used quite extensively in recent years for making charcoal blooms; in 1882 the output was 48,000 tons in the United States, and as late as 1888 it was 14,000 tons.

In Germany the early iron-makers increased the size of the furnaces, and in the sixteenth century some were fifteen feet high and five feet in diameter, but the pasty ball was still the end desired, and the whole front of the furnace was torn out each time to pull out the mass, which was then forged into bars of wrought-iron. At a later time, possibly in the sixteenth, and perhaps not till the

seventeenth century, furnaces were built as much as twenty-five feet high, and thereby a temperature was sometimes obtained high enough to cause the pasty iron to absorb carbon and become liquid. When this was done, the blast furnace was born, and the world came into possession of a new metal—pig-iron—meaning by this term that iron sponge has been exposed at a high temperature to carbon and to the earthy components of ore and fuel, and by virtue of this high temperature has absorbed about four per cent. by weight of carbon and certain proportions of silicon, phosphorus and sulphur, etc. These elements, especially carbon, make the iron more fusible, so that it can be cast in forms, and also make it brittle as compared with wrought-iron. Some of the pig-iron made in early times was used for castings, but a great proportion was worked into wrought-iron in almost the same kind of hearth that has just been described for making iron directly from the ore. The pig was melted down with charcoal and exposed to the air blast, both during fusion and afterward. The same pasty mass was produced, but the output of a fire was greatly increased by having pig-iron instead of ore.

This whole system of iron-making is primitive, and is wasteful of labor and fuel. Moreover, it is necessary that charcoal be used, because all coal and coke contains sulphur, and when the fuel is in contact with the iron for a long time, as in the old hearths, this sulphur will be absorbed by the iron, and the product will be red-short and worthless. Charcoal contains no sulphur, so that the old furnaces could work at low temperatures and long exposures. In modern blast furnaces, where coke is the almost universal fuel, it is necessary to carry regularly a higher temperature than an old charcoal furnace ever knew. The following pages will not discuss the making of iron in the old sinking fires, because modern metallurgy counts this as a special process, and recognizes as standard only the making of pig-iron in a blast furnace, while the crucible, the open-hearth furnace and the Bessemer vessel convert this into steel.

CHAPTER II.

THE BLAST FURNACE.

SECTION IIa.—*General description.*—A modern blast furnace is a cylinder lined with fire brick, about 90 feet high and about 20 feet in diameter at the largest place. This furnace is filled with a mixture of coke, iron ore and limestone, and air is blown in near the bottom through openings called tuyeres. The coke is partially burned in the immediate neighborhood of the tuyeres, but only partially; it forms a gas, carbonic oxide (CO), and this gas rising through the ore in the upper part of the furnace robs it of its oxygen, and reduces the iron to the metallic state. The air blown into the furnace is first heated to a dull red heat by passing it through stoves, these stoves being previously heated by burning in them the gases escaping from the top of the furnace; only a part of these gases is needed for heating the air, the remainder being used under boilers for the generation of steam. As the air is red hot when it enters the tuyeres, and as it immediately meets glowing coke, a very high temperature is created, so that this region immediately about the tuyeres is called the "zone of fusion." It is here that the real melting occurs, but much of the reduction of the ore to the state of metallic iron takes place in the upper part of the furnace. This reduction is never complete, and some ore reaches the zone of fusion in a nearly raw state; but in this zone the high temperature quickly completes all reactions—the ore is rapidly reduced, the earthy impurities unite with the lime and are fused into slag, while the metallic iron melts and is collected in the hearth below the tuyeres.

Fig. II-A shows a modern American blast furnace provided with water-cooled plates set into the walls of the lower part of the furnace to prevent the wearing away of the walls, thereby preserving the original slope and size of the bosh. Fig. II-B shows another device used at Steelton to attain the same end. The walls of the bosh are made very thin and are enclosed in a tight boiler-iron casing, against

which water is constantly played. The cooling effect penetrates the thin brickwork, while the cooled iron shell alone is competent to

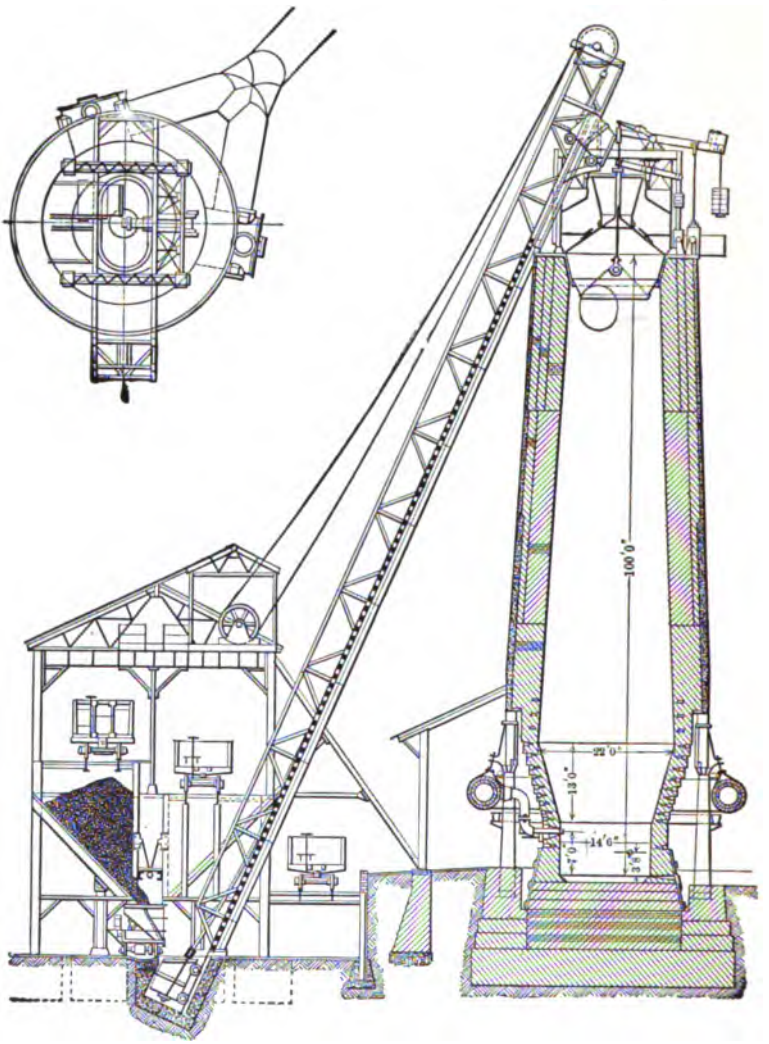


FIG. II-A.—BLAST FURNACE AT JONES & LAUGHLINS, PITTSBURG, PA.

withstand the erosion of the stock, even if the brickwork be worn away. A furnace in proper condition tends to deposit carbon upon

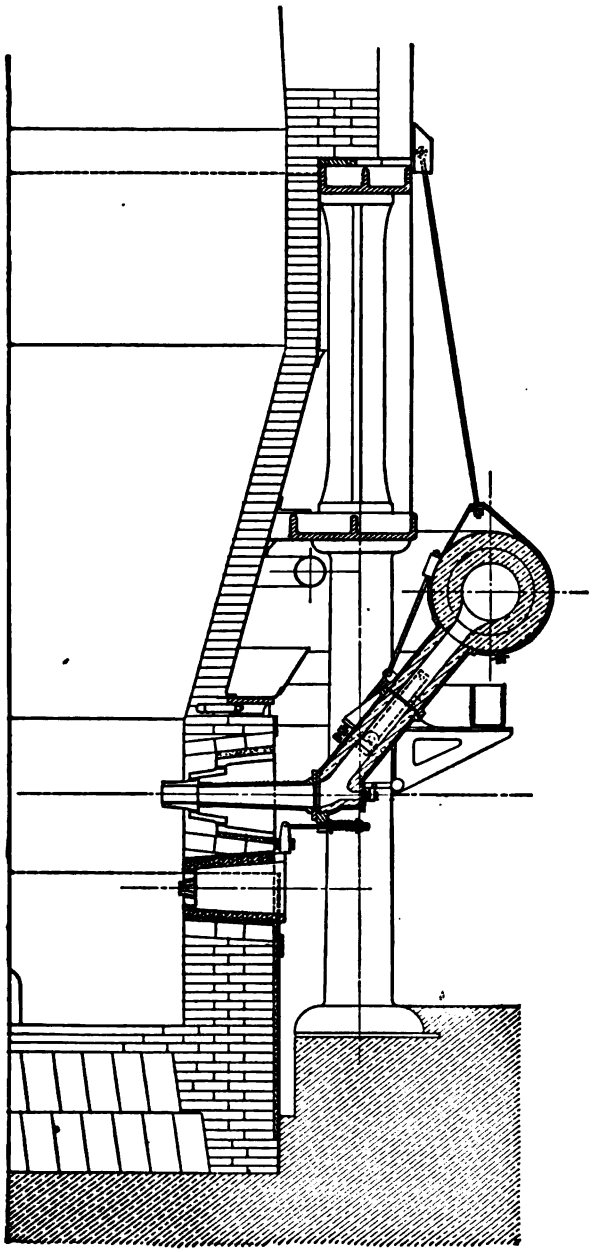


FIG. II-B.—BOSH CONSTRUCTION AT STEELTON, PA.

the walls, so that even if a patch of lining is carried away, the loss is restored by the furnace itself by a carbon lining upon the cold plate.

Half a century ago there were few furnaces in the world as much as 50 feet high, but it was found that an increase to 70 feet saved fuel and increased the output. It was natural to assume that a greater height would insure greater economies, and during the last quarter of a century there has been a race in Eastern America to build the biggest furnace and turn out the most iron. In 1875 a big furnace was 80 feet high and made 100 tons per day. Now there are stacks 100 feet high, making 600 tons. It is probable that this is the commercial limit of size, not on account of inability to operate a larger furnace, but because in a steel works it is more convenient to have six furnaces, making 400 tons per day, than to have four furnaces making 600 tons, as an accident to one unit causes less interruption to tributary departments. It is also found that, on Lake Superior ores, little is gained by increasing the height beyond 90 feet.

SEC. IIb.—*Ore.*—Three kinds of ore are used in the making of iron: (1) hematites, (2) carbonates and (3) magnetites. They never occur in a pure state, being mixed with earthy materials, but in discussing their composition it is necessary to consider the iron mineral by itself.

(1) Hematite (Fe_2O_3) contains exactly 70 per cent. of iron, but in addition to ordinary earthy impurities it carries water of crystallization in amounts up to 20 per cent. When the proportion of this water is low the ore is called a "red" or "brown" hematite, while the hydrous varieties are called "soft" hematites, or "limonites," although this latter term should only be applied to bog ores containing about 20 per cent. This water of crystallization can only be removed by heating the ore nearly to a red heat. Oolite is a variety of hematite composed of small spherical grains, each grain being a kernel of foreign matter surrounded by iron ore. When the foreign matter is silica, as in some places in Alabama, the ore is well nigh worthless, but when it is partly lime, as in the Minette district of Germany and Luxemburg, the ore is "self-fluxing." If such an ore carries 40 per cent. of iron and sufficient lime so that no stone is needed in the furnace, it is as valuable as an ore with 50 per cent. of iron and no lime. It is

necessary to keep this fact in mind in considering the results obtained in Western Germany from ores running under 35 per cent. in iron.

Red hematite is the most desirable of all iron ores. Most of the Lake Superior deposits are of this variety, and they alone supply as much ore as comes from any other one country, while the Bilbao region in Spain, the Minette district of Lothringen and Luxemburg, the West Coast of England and the beds of Alabama, all mine the same mineral and are of world-wide importance. Of lesser interest are the deposits in the basin of the Don in Southern Russia, the southeast coast of Cuba, the Tafna beds in Algeria and the Bell Island mines in Newfoundland.

(2) Carbonate ($FeCO_3$), called also spathic ore, black band, clay iron stone, etc., contains 48.3 per cent. of iron. Very little is used in the United States, but it is the basis of the great Cleveland district near Middlesborough, England, and of the iron industry of Bohemia and Styria, and is produced in large quantities in Hungary and Spain. In former days the Spanish mines rejected this ore as inferior, but it is now mined extensively. Almost everywhere spathic ore is roasted. The kilns are such as are used for limestone, and sometimes coal is mixed with the ore, while at other places tunnel head gases are used for fuel. The fuel needed is less than might be supposed, from 75 to 100 pounds of coal per ton of ore being the usual practice, because the expulsion of the carbonic acid leaves the iron in the form of FeO, and this burns to Fe_2O_3, so that for every ton of raw ore the burning of the iron produces an amount of heat equal to what would be produced by 35 pounds of coal.

(3) Magnetite (Fe_3O_4) contains 72.41 per cent. of iron. It is strongly attracted by the magnet, while other iron ores are only slightly influenced by strong currents. It is currently believed that more fuel is required for smelting magnetite than for hematite, but recent results with Swedish magnetic ores in German and Austrian furnaces indicate that the difficulties may have been overrated. Magnetite is found in enormous quantities in central and northern Sweden and in the northeastern part of the United States. In both countries there are some rich beds, and some of great extent that are lean in iron. Within the last few years great strides have been made in the concentration of these ores, both in Sweden and

America. Given a large tract of land with a deposit of 40 per cent. magnetite, and assuming that it can be bought for such a sum that the cost per ton of ore is nominal, and assuming that cheap transportation to market is assured, it is then possible to crush and concentrate, obtaining a product running, say, 65 per cent. in iron, and compete with ores that are burdened with a heavy royalty at the mine and a large transportation charge. The stumbling-block which has prevented the development of magnetic concentration is making the fine concentrate into bricks. This problem seems now to be solved either by using a rotary furnace to clinker the concentrate, or by pressing into bricks without water, and heating these bricks in a continuous furnace until the particles are stuck together, but not fused.

It seems certain that work will be done in the future on the concentration of lean magnetites in New Jersey, New York and Pennsylvania, but the cost of the operation is so great that only favored localities can look forward to a profitable enterprise. Many deposits, both in Sweden and in New York, are contaminated with titanium, and concentration cannot be regarded as successful unless this is eliminated. Titaniferous ores have been worked in small quantities for generations, but every attempt to employ them upon a large scale, especially in the manufacture of steel, has been a failure. A favorite argument in favor of titanium is the use of Taberg ores in Sweden. It may be well, therefore, to say that there are two Taberg deposits: one a good ore with no titanium; the other, the famous Iron Mountain, carrying 31 per cent. iron and 6 per cent. of titanium oxide. This latter ore has been worked in the past, but operations dwindled until in 1892 only 50 tons were mined. The mountain is still there, but it is untroubled by a pick.

SEC. IIc.—*Fuel.—Charcoal* was the almost universal fuel a century ago, but to-day it is only in Sweden and in the Ural Mountains that it is the base of a great industry; in both these places it is the only fuel available. In the United States the output of charcoal iron is insignificant compared with coke iron, but we make two-thirds as much as Sweden, and the amount is increasing year by year in answer to a demand for an iron of great toughness and wearing qualities, the car-wheel trade absorbing most of the output. A large share of the product in this country is made in Michigan, and the charcoal is a by-product from chemical works.

Ordinary wood when dry contains about 50 per cent. water; after distillation the charcoal carries 85 to 90 per cent. of carbon, and a bushel, American official rating, is 1.59 cubic feet and weighs 20 pounds. In Sweden the weight is much less. The consumption of charcoal is reported in Sweden as low as 1550 pounds per ton of iron. One furnace in America reports 1760 pounds and an output of 1000 tons per week.

Anthracite is used in eastern Pennsylvania, but to much less extent than is usually supposed, as the statistics tabulate, as an anthracite furnace, one that occasionally employs hard coal as a portion of the charge. In South Russia, anthracite is also used in limited measure, but other countries call by that name a coal which, in the United States, would be classed as a hard bituminous. In Scotland raw coal is charged because the so-called Scotch splint coal contains only a small proportion of volatile matter.

Coke may be looked upon as the standard fuel. It must be firm and strong to resist crushing in the furnace, and porous so as to burn rapidly; it should have less than 12 per cent. of ash and less than 1.0 per cent. of sulphur, and less than .02 per cent. of phosphorus if the pig iron is to be used in making acid steel. The best coke comes from Durham, on the northeast coast of England, from Connellsville in Pennsylvania, and from Westphalia in western Germany.

SEC. IId.—*Amount of ore and fuel required.*—If the ore charged in a furnace contains 60 per cent. of iron it will take just one and two-thirds tons to make one ton of metallic iron, but as pig-iron contains silicon, carbon, sulphur and phosphorus, one ton of pig-iron can be made from one and two-thirds tons of ore containing only 55 per cent. of iron if much phosphorus is present, or 57 per cent. if the phosphorus is low. It requires about one ton of coke to smelt this ton of iron, sometimes less, sometimes more. If too little fuel is used the furnace is cold, the iron is high in sulphur, the slag is not fluid and the hearth "chills." If too much is used the iron is high in silicon, and the hot zone of fusion, instead of being confined to a small area near the tuyeres, extends upward, fusing the stock and making it stick to the walls, thus causing irregular working.

SEC. IIe.—*Limestone.*—In operating a blast furnace a certain amount of limestone is necessary. As the stone sinks with the rest

of the stock it becomes red hot, whereupon the carbonic acid is expelled, as in an ordinary lime kiln, and the burned lime descends to unite with the silica, which is present in the ore and in the ash of the coke. Without this lime the silicious material would scarcely be fusible, but when the proper quantity is added the lime, silica and earthy constituents of ore and ash unite to form a fusible slag that flows readily from the cinder notch. The proper proportion of limestone depends upon the impurities in the ore, in the coke and in the stone itself. Some furnaces run on a mixture of ores averaging not over 6 per cent. of silica, while other furnaces average 10 per cent. The stone itself varies in different localities from 1 to 6 per cent. in silica, while the percentage of ash in the coke may be anywhere from 6 to 15 per cent. A furnace running on silicious ores and limestone and a poor coke will need twice as much limestone as one carrying good ore and fuel, while with such poor material more fuel will be required and twice as much slag produced. An important duty of the lime after it has been fused into slag is to carry away the sulphur in the coke. Much difference of opinion exists as to the proper and possible chemical composition of blast-furnace slags. Roughly, it may be said that the silica should be between 30 and 40 per cent. and the lime between 40 and 50 per cent., and that when the slag is made more basic the temperature must be raised, as each increase in lime raises the melting point.

SEC. IIf.—*The use of burned lime.*—In 100 pounds of pure limestone there are 56 pounds of CaO and 44 pounds of carbonic acid gas (CO_2). As soon as the stone reaches a red heat in the blast furnace this CO_2 is driven off and rises through the overlying stock, some of it uniting with the coke according to the following reaction:

$$CO_2+C=2\ CO.$$

This shows that every pound of carbon in the stone carries away a pound of carbon from the coke; that if a thousand pounds of stone be used to one ton of coke, then 6 per cent. of all the fuel is destroyed by the stone, while if twice that amount of stone be charged, then 12 per cent. is lost. To prevent this waste, some furnaces in Middlesborough, England, as well as elsewhere, have calcined the stone before charging, and there are papers on record showing a very con-

siderable gain in fuel,* but it is a matter of great doubt whether there is any important saving in the long run. The Middlesborough furnaces should profit more than others, as they carry twice as much stone as most American furnaces, but the practice has made little headway in that district. One reason for the failure is that the ordinary methods of burning lime do not expel all the gas, so that only a part of the benefit can be expected. Another reason lies in the fact that when burned lime is put into the blast furnaces it is exposed to the action of carbonic acid gas (CO_2), and, although this gas is expelled from stone at a red heat, it is absorbed again at a lower temperature, so that immediately after being charged into the furnace, this burned lime reverts to the condition of limestone, which sinks down with the charge and acts in the same manner as if it had never been burned.

SEC. IIg.—*The blast.*—On another page, under the discussion of Tunnel Head Gases, are given calculations on the amount of air needed for a furnace and on the heat required to bring it to the desired temperature. In America, a temperature of 1000° to 1100° F. is often considered sufficient, and on Mesabi ores a higher heat is believed to give trouble from slips. In foreign countries higher temperatures are maintained. It is a common practice abroad to have several furnaces on one common air main, but the modern method is to have an independent engine for each furnace in order that a constant quantity of air be forced into the tuyeres without any regard to the resistance caused by internal conditions. Let it be arbitrarily assumed that a coke fire with cold blast will give a temperature of 2500° F., and that if the blast be heated to 1000° F. a temperature of 2900° F. will be obtained. If, then, it is necessary to melt 100 pounds of a metal that fuses at 2700° F., it might be possible to do so with 100 pounds of coke with hot blast, when it would be impossible to do it at all with cold blast. In this case the heating of the air to 1000° F. has worked a revolution in fuel economy, but it by no means follows that an increase to 1100° or 1200° will save much more, for if 1000° is sufficient for the work in hand, an increase beyond that point may be of little value.

These arbitrary assumptions illustrate the use of hot blast in furnaces, for it was the first step that produced the revolution by obtaining a temperature that changed all the operating conditions.

*Journal I. & S. I., Vol. I, 1898, p. 69.

Heating the blast to 800° F. resulted in a great saving of fuel; a further heating to 1400° F. made a further saving, but much less than might be expected; while an increase to 1800° F. may not be justified unless the ore is reduced with difficulty.

SEC. IIh.—*The temperature attained by hot blast.*—The temperature of any fire may be found by dividing the sum total of heat present by the specific heat of the resulting products. We use the heat *present* and not the heat *produced,* because the production of heat from one kilogramme of coke is the same whether hot or cold air is used, but with hot air the amount present is greater by just the quantity contained in the air. The specific heat of the coke will also be greater when hot blast is used. The specific heat of gases varies with the temperature: at 0° C. it takes 0.306 calories to heat one cubic meter of air 1° C., but at 2000° C. it takes 0.360 calories. The formulæ for finding the specific heat of some ordinary gases are as follows, the temperatures being Centigrade and the results in calories:

$$N,\ CO,\ O \text{ and } H = 0.306 + 0.000027t$$
$$CO_2 = 0.374 + 0.00027t$$

The specific heat of carbon above 1000° C. is 0.5, but below 1000° C. it is less, so that the total heat in 1 kg. of carbon at t° (when t is above 1000°) is approximately 0.5—120. Assuming the value of 1 kg. carbon as 2450 calories when burned to CO, as is the case at the tuyeres of a blast furnace, the calculation for a temperature of 1000° F.=540° C. will be as follows:

1 kg. C+4.47 c.m. air=1.87 c.m. CO+3.53 c.m. N	
Heat in air $4.47 \times .320 \times 540 =$	772
Heat in carbon	$0.5t -$ 120
Heat in carbon and air	$0.5t +$ 652
Heat from combustion	2450
Total heat in 5.40 c.m. of products	$0.5t + 3102$
Heat in 1 c.m.	$.0926t + 574.1$

$$\text{Therefore, } t = \frac{.0926t + 574.1}{0.306 + .000027t} = 2122$$

When the air is 0° C. the temperature of the fire is about 1560° C., while if the blast is 1000° C. it will be 2400° C. Each increase of 100° in the temperature of the air raises the resulting temperature about 80°, whether the scale be Centigrade or Fahrenheit.

SEC. III.—*Vapor in the atmosphere.*—Accompanying are the weather records at Harrisburg, Pa., the figures being averages of the years 1901, 1902 and 1903. The climate is representative of the northeastern portion of the United States. The year is divided into the "wet" half and the "dry" half. The percentage of humidity is about the same in winter as in summer, but the actual amount of moisture in the warm or wet half of the year is about three times as much as in the cold or dry half, while in July the content is nearly six times as much as in February.

Dry half.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	Av'ge.
Temperature	42	30	29	28	44	51	37
Humidity, per cent.	70	76	74	69	69	62	70
Grains per cubic foot:							
Saturation	3.08	1.98	1.91	1.83	3.34	4.26	2.73
Actual	2.16	1.50	1.41	1.26	2.30	2.64	1.88
Wet half.	**May.**	**June.**	**July.**	**Aug.**	**Sept.**	**Oct.**	**Av'ge.**
Temperature	62	68	76	71	65	55	66
Humidity, per cent.	64	71	74	79	77	72	73
Grains per cubic foot:							
Saturation	6.17	7.60	9.79	8.31	6.83	4.92	7.28
Actual	3.95	5.40	7.24	6.56	5.30	3.54	5.33

This moisture, when blown into the blast furnace, is decomposed, one kg. of water forming 1-9 kg. of hydrogen and 8-9 kg. of oxygen. This decomposition absorbs a quantity of heat equal to that produced by burning a similar weight of hydrogen= $\frac{30000}{9}$ =3333 calories. On the other hand, the oxygen set free unites with the coke.

$$8\text{-}9=0.89 \text{ kg. } O+0.67 \text{ kg. } C=1.56 \text{ kg. } CO$$

producing 1650 calories, the net absorption being 3333—1650= 1683 calories per kilogram or 3030 B.t.u. per pound of water vapor admitted. This absorption of heat immediately in front of the tuyeres must be compared with the creation of heat at the

same spot, and the combustion in that portion of the furnace is the union of carbon with oxygen to form carbonic oxide (CO), so that one kilogram of carbon produces 2450 calories, and one kilogram of coke 2080 calories. One kilogram of water therefore absorbs as much heat as is produced by 1683÷2080=0.8 kg. of coke, and one pound of water=0.8 pounds of coke.

The importance of removing the vapor in the air has long been admitted, but it is only recently that it has actually been done. In the *Journal I. & S. I.*, Vol. II, 1904, Gayley describes the results obtained by passing the air through a refrigerating chamber and cooling it to 25° or 30° F. The air coming from this chamber is necessarily saturated, so that the gain is not as much as might at first sight be expected. Thus if an atmosphere of 36° F. and 70 per cent. humidity, such as is often found in winter, be cooled to 27° F., there will be no deposition of moisture, as we will merely have air of 27° F. and 100 per cent. humidity, but the cooling of the air in summer precipitates large quantities of water. In the conditions above given for July, with 76° F. and 74 per cent. humidity, the process of cooling to 27° F. would remove three-quarters of all the

Grains of water per cubic foot of air.			
	Per cent. Humidity.		
Temperature.	100	70	40
0	0.51	0.36	0.20
12	0.85	0.60	0.34
22	1.35	0.95	0.54
32	2.08	1.46	0.83
42	3.08	2.16	1.23
52	4.50	3.15	1.80
62	6.17	4.32	2.47
72	9.24	6.47	3.70
82	12.99	9.09	5.20
92	18.09	12.66	7.24
102	25.00	17.50	10.00

moisture. Gayley states that for 13 days an average of 69 pounds of water were removed from the blast per ton of iron. It has been shown that according to theory 1 pound of water=0.8 pound of coke, so that the above precipitation represents a saving of 55 pounds of coke per ton of iron; but this theoretical heat valuation is only a part of the problem, for a more important matter is the attainment of regular conditions. It is essential that a

blast furnace shall not get cold, and in ordinary practice this can only be prevented by carrying a slight excess of fuel to allow for variations in the air and in the burden. When the greater variable—the air—is made a constant from hour to hour, the excess may be reduced to a minimum.

The amount of water in the air at different temperatures and at different degrees of humidity is given herewith (see page 48).

SEC. IIj.—*Metallurgical conditions.*—In a charcoal blast furnace no sulphur exists in the fuel, and if there is none in the ore the only problem is to smelt the iron and to have a cinder fluid enough to carry away the earthy materials and not fluid enough to attack the lining. When coke is the fuel, a more basic slag is needed to hold the sulphur, and a higher temperature to keep this slag fluid. With too little fuel the slag will not run freely, and the iron will be high in sulphur, while with too much fuel the iron will be high in silicon and the furnace will tend to stick and hang. In short, the daily work of the furnaceman is to remove sulphur with the least amount of fuel. Many metallurgical conditions are involved in this problem, among which are the following:

(1) The amount of slag.
(2) The composition of the slag.
(3) The temperature of the furnace.

(1) *Amount of slag:*

In case the ore is very pure, say with only two per cent. of silica, and the coke and stone are moderately low in silica, then it does not suffice to add just enough lime to satisfy the silica, because not enough cinder will be produced to carry away the sulphur of the coke, so that silicious materials or impure ores must be added. The same course of procedure may be necessary even in moderately silicious ores, when they contain abnormal amounts of sulphur.

(2) *Composition of the slag:*

The basis of every cinder is silicate of lime, the silica coming from the ore and ash, and the lime from the stone, but there are always other elements present. Alumina and magnesia are invariably found in the ore or in the stone, or in both, and they constitute a considerable proportion of the slag, and vary within wide limits. The allowable proportion of magnesia is in doubt.

Ledebur* prefers pure limestone to those containing magnesia, and Bell† agrees that lime has an affinity for sulphur, whereas magnesia has little or none. On the other hand, Phillips‡ says that dolomite is quite as efficient as limestone and more so when low sulphur is

TABLE II-A.

Composition of Blast Furnace Slags.

	Slag.							Iron.		Remarks.
	SiO_2	Al_2O_3	CaO	MgO	FeO	S	Total not including S.	Si	S	
1	33.10	14.92	40.76	9.67	.....	.....	98.45	3.37	tr.	Cuban ore, hot furnace.
2	32.27	14.57	41.02	10.30	.....	.....	98.16	3.18	tr.	" " " "
3	24.26	11.53	40.25	13.28	.....	.....	98.32	4.81	.01	" " " "
4	32.68	13.50	43.28	9.44	.....	.....	98.90	1.25	.06	" " warm
5	32.28	9.38	46.95	9.52	.....	.....	98.13	0.70	.11	" " cool.
6	34.50	7.94	46.47	10.47	.....	.....	99.38	0.69	.05	" " "
7	34.98	12.05	41.33	9.62	....	....	97.98	2.60	.03	Spanish ore, hot furnace.
8	34.70	11.44	41.27	9.96	.....	.....	97.37	2.32	.02	" " " "
9	33.68	11.93	45.96	6.69	.....	.....	98.26	1.27	.02	" " " "
10	29.86	12.04	45.20	11.41	.....	....	98.51	1.27	.02	" " " "
11	28.95	12.04	49.30	8.46	....	.....	98.75	.57	tr.	" " cool furance.
12	30.62	10.47	49.13	7.49	.....	.....	97.71	.26	.02	" " " "
13	32.55	11.13	47.16	6.61	.....	....	97.45	.15	.03	" " " "
14	30.08	11.44	46.36	8.76	.....	.....	96.64	.58	.03	" " " "
15	31.46	11.50	44.85	10.41	.....	.....	98.22	.20	.07	" " " "
16	36.08	12.85	41.69	7.25	0.54	1.62	98.41	2.15	.020	Lake ore and part anthracite coal: mostly Connellsville coke. — Hot furnace.
17	37.19	12.65	35.47	11.32	0.90	1.70	97.53	1.92	.029	Fairly hot.
18	36.86	10.74	42.46	6.62	0.63	1.54	97.31	1.50	.028	" "
19	32.06	11.97	42.46	10.25	0.63	1.76	97.37	1.59	.032	" "
20	33.57	10.65	44.11	8.55	0.81	1.74	97.69	0.94	.017	Normal.
21	35.38	11.76	38.19	12.32	0.90	1.60	98.53	1.13	.040	"
22	36.35	10.21	40.10	10.96	0.99	1.28	98.60	0.66	.095	Cool.
23	33.70	12.56	38.12	11.60	0.32	0.96	98.30	0.50	.101	"
24	35.11	14.21	28.41	22.38	.....	.....	100.12	1.37	.048	Lake ore and Connellsville coke. — Av. of 8 weeks
25	35.10	14.75	27.95	22.28	.....	.....	100.08	1.85	.038	" 7 weeks
26	35.84	14.34	32.71	17.46	.....	.....	100.35	1.60	.034	" 7 weeks
Averages for hot furnaces—										
	33.21	13.67	40.68	11.08	.....	.....	98.64	3.79	tr.	Cuban ore.
	34.84	11.75	41.30	9.79	.....	.....	97.68	2.46	.025	Spanish ore.
	31.77	11.98	45.58	9.05	.....	.....	98.38	1.27	.020	" "
	35.55	12.05	40.52	8.86	0.68	1.66	97.66	1.79	.027	Lake ore.
Averages for moderate or cool furnace—										
	33.15	10.27	45.57	9.81	.....	.....	98.80	0.88	.07	Cuban ore.
	30.73	11.32	47.36	8.35	.....	.....	97.75	0.35	.03	Spanish ore.
	34.75	11.30	40.12	10.86	1.26	1.40	98.29	0.81	.063	Lake ore.
	35.35	14.43	29.69	20.71	.....	.....	100.18	1.61	.040	" "

NOTE—All slags are from Steelton furnaces except Nos. 24, 25 and 26. The ore mixture was the same in all the cases where Spanish ore was used.

required. Firmstone§ argues that under certain conditions the sulphur is *reduced* by substituting dolomite for limestone, and states

* *Kaerntner Zeitschrift*, No. 2, 1881, p. 53. † Manuf. Iron & Steel p. 58.

‡ Iron Making in Alabama; Ala. Geol. Survey, 1898, p. 73.

§ *Trans.* A. I. M. E. Vol. XXIV, p. 498.

that with pure lime and a silica content of 39 to 40 per cent. the cinder "slacked," but with dolomite the silica could be reduced to 35 per cent. and the furnace worked better. He refers to various investigators who claim that a high content of magnesia gives rise to the production of spinel, an infusible compound of alumina, lime and magnesia, and argues that the formation of this mineral depends upon the presence of a large proportion of alumina, as well as magnesia, so that no harm will result from 20 per cent. of magnesia in the slag if the alumina is under 10 per cent.

In regard to alumina, it is stated by Elbers* that if the percentage of silica be low it acts as an acid, and hence increases the fluidity of the slag, but if high it acts as a base, and thus lowers the fusing point. Phillips† says that in every-day practice and with slags of 33 and 36 per cent. silica, the alumina is considered as silica.

Many of the accurate limitations set by special investigators after a limited series of experiments are erroneous. Thus I have the slag records of a furnace for four months, where the cinder was fairly constant and averaged as follows, in per cent.:

SiO_2, 35 Al_2O_3, 14.5 CaO, 28 MgO, 22

This upsets any theory that high alumina and high magnesia are incompatible. In the same way, experiments made at Steelton show that alumina can be carried above 35 per cent. with perfect elimination of the sulphur and good working of the furnace, and it appears to replace, to some extent, both silica and lime, and may therefore be regarded as merely passively diluting the cinder. This will be evident from the following series of slags, arranged in order of increasing alumina. Each column is the average of several casts from a furnace operating for over a week on an aluminous burden.

SiO_2	34	34	29	25
Al_2O_3	10	16	27	33
CaO plus MgO	54	45	40	39

The general range of blast-furnace slags is illustrated in Table II-A.

*Berg- und Huttenmannische Zeitung, Vol. XLVII. p. 253.
† Ala. Geol. Survey, 1893, p. 45.

(3) *Temperature of the furnace:*

The elimination of sulphur is assisted by a high temperature; but temperature alone is not sufficient, for with a silicious slag the iron may be high in sulphur, even though the furnace be hot; but any particular slag will carry more sulphur with a hot furnace than when the hearth is cold. Hence, a slag which is quite suitable for a hot furnace must be made more limey if the temperature is reduced, or the iron will be higher in sulphur. On the other hand, a limey slag will not run fluid in a cool furnace, so that the furnaceman is held between narrow limits.

It is essential in practice, in addition to the removal of sulphur, that the content of silicon in the iron be regulated. This can be done by a proper control of the temperature and of the slag. A rise in temperature gives higher silicon in the iron, because the coke has then a greater affinity for the oxygen of the silica and sets free the silicon. On the other hand, an increase in the amount of lime gives lower silicon, because the silica is needed by the lime to form a slag. The amount of silica present has something to do with the result; a furnace working on impure ores may handle twice the weight of silica per ton of iron that is carried by a furnace on a rich burden, and make twice the weight of slag, and with this greater exposure of silica to reduction the tendency will be toward a higher silicon in the iron. The control of the silicon and the control of the sulphur constitute two problems, quite separate from one another, and yet closely related. The determining conditions may be grouped under four general divisions:

(1) An iron with high silicon and low sulphur is made by running the furnace at a high temperature with a slag sufficiently basic to hold the sulphur, but not basic enough to keep silicon from being reduced.

(2) An iron with low silicon and low sulphur is made by using a lower temperature with a somewhat more basic slag, or a high temperature with a much more basic slag.

(3) An iron with low silicon and high sulphur is made by using a low temperature with a slag not sufficiently basic.

(4) An iron with high silicon and high sulphur is made by using a high temperature with a slag not sufficiently basic.

The presence of manganese complicates the metallurgy of the furnace, but does not change any of the foregoing laws. An acid slag

carries away considerable manganese, but if the cinder is basic most of the manganese is reduced and appears in the iron. In the making of spiegel iron and ferro-manganese, it is necessary to have a strongly limey cinder to prevent waste of manganese, so that the silicon is usually low in these alloys. It is possible, however, by special care, to make a silico-spiegel with as much as 11 per cent. of silicon and 18 per cent. of manganese, this being used as a recarburizer in steel making.

SEC. IIk.*—*Chemical reactions.*—A blast furnace may be looked upon as a colossal gas producer, in which there is a column of coke 70 ft. high ranging in temperature from a white heat at the tuyeres to a black heat at the tunnel head. As soon as the air strikes the white-hot coke there is an immediate formation of carbonic acid, followed by an instantaneous reaction, by which the carbonic acid so produced unites with more carbon to form carbonic oxide. This reaction is consummated quickly and with thoroughness, so that if the furnace held only coke, the gas from the top would be almost entirely carbonic oxide and nitrogen; but the furnace contains also iron oxide, and this complicates the matter, for the carbonic oxide reacts upon the oxide of iron, forming carbonic acid and metallic iron. The reactions between carbonic acid (CO_2), carbonic oxide (CO), carbon, ferric oxide (Fe_2O_3), ferrous oxide (FeO) and spongy iron (Fe) are dependent upon the temperature and upon the composition of the gases. The phenomena were investigated by Bell many years ago, and Fig. II-C, as well as the following discussion, is founded on his experiments.

Carbonic oxide begins to reduce Fe_2O_3 at about 250° C. (480° F.), but the action is not rapid until a temperature of 400° C. to 450° C. is reached (say 800° F.), when the Fe_2O_3 is converted into Fe_3O_4, or after longer exposure, to Fe_6O_7. Following are some of the chemical relations between carbonic oxide and the usual iron oxides, in the order in which they occur in the blast furnace:

(1) $3\ Fe_2O_3+CO=2\ Fe_3O+CO_2$.
(2) $Fe_3O_4+CO=3\ FeO+CO_2$.
(3) $FeO+CO=Fe+CO_2$.

Each of these is exothermic—i.e., it produces heat.

* I am indebted to Mr. J. W. Dougherty, superintendent of the Pennsylvania Steel Co., at Steelton, for a careful supervision of this section.

FIGURE II-C.

Blast Furnace Reactions as Determined by the Temperature.

Note.—The word "complete" means *practically* complete.

1000°C	$CO_2+C=2CO$
950°	
900°C	
850°	
800°C	$CaCO_3=CaO+CO_2$ $FeO+C=Fe+CO$ (complete)
750°	
700°C	$FeO+C=Fe+CO$ (begin)
650°	
600°C	Carbon deposition ceases $Fe_3O_4+CO=3FeO+CO_2$ (complete)
550°	$CO_2+C=2CO$ (begin)
500°C	
450°	$3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (complete) $Fe+CO_2=FeO+CO$
400°C	$Fe_2O_3+3C=2Fe+3CO$ (begin) $3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (rapid)
350°	
300°C	$Fe+CO_2=FeO+CO$ (begin)
250°	$2Fe_2O_3+8CO=7CO_2+4Fe+C$ (begin carbon deposition) $3Fe_2O_3+CO=2Fe_3O_4+CO_2$ (begin)
200°C	

Carbon begins to reduce Fe_2O_3 at about 400° C. (750° F.). The reactions between carbon and the usual oxides are as follows:

(4) $Fe_2O_3+3\ C=2\ Fe+3\ CO.$
(5) $Fe_3O_4+4\ C=3\ Fe+4\ CO.$
(6) $FeO+C=Fe+CO.$

Each of these reactions is endothermic—i.e., it absorbs heat.

The carbonic acid (CO_2) formed by the reduction of iron oxide by carbonic oxide (CO), or by carbon, is an oxidizing agent, and by a change in temperature there may be a reversal of the reduction just performed, according to the following reactions:

(7) $2\ FeO+CO_2=Fe_2O_3+CO.$
(8) $2\ Fe+3\ CO_2=Fe_2O_3+3\ CO.$

The first creating heat and the second absorbing energy. These reactions depend upon both the temperature and the dilution of the gas with carbonic oxide. At high temperatures the action is strong, and considerable carbonic oxide must be present to avoid reoxidation. The main landmarks of the relations may be thus summarized:

(a) Carbonic acid (CO_2) begins to oxidize spongy iron at 300° C. (570° F.).

(b) Carbonic acid (CO_2) begins to unite with carbon at 550° C. (1020° F.), and the reaction is complete at 1000° C. (1830° F.).

(c) The reduction of metallic iron depends upon the percentage of carbonic acid (CO_2) in the gases, but the critical content of CO_2 depends upon the temperature, as follows:

At a white heat a gas containing CO_2=10%, CO=90%, will not reduce metallic iron from the oxide.

At a full red heat a gas containing CO_2=32%, CO=68%, will not reduce metallic iron.

At a low red heat a gas containing CO_2=60%, CO=40%, will not reduce metallic iron.

A mixture of CO_2=50%, CO=50%, passed over spongy iron at a white heat oxidizes it to FeO, while if passed over Fe_2O_3 reduces it to FeO.

The reactions in the upper part of the blast furnace are not simple processes of reduction like reactions (1) to (6), or oxidations like (7) and (8). While these actions are progressing there is a deposition of carbon, according to relation (9),

(9) $2\ Fe_2O_3+8\ CO=7\ CO_2+4\ Fe+C.$

It is stated by high authority that carbon deposition cannot take place without oxidation of metallic iron by carbonic acid (CO_2), or by carbonic oxide according to the relation (10) or (11),

$$(10)\ Fe+CO=FeO+C,$$
$$(11)\ 2\ Fe+CO_2=2\ FeO+C,$$

but it is difficult to understand how these reactions can take place in the upper zone of the blast furnace, since at the temperatures existing the reactions (1) and (9) are the only ones possible, and no metallic iron can exist except through reaction (9), which calls for carbon deposition, and this reaction produces metallic iron instead of oxidizing it. It may be true that at higher temperatures the great bulk of carbon deposit is dependent upon, or at least is associated with, an oxidation of metallic iron by carbonic acid (CO_2) or carbonic oxide (CO), but the testimony indicates that the first of the carbon deposit is formed where the temperature is insufficient for the formation of metallic iron save by the simultaneous formation of impregnating carbon. Moreover, if metallic iron were formed it could not be oxidized by carbonic acid (CO_2), since reaction (12) does not begin until a temperature of 300° C.

$$(12)\ Fe+CO_2=FeO+CO.$$

(510° F.) is reached and does not become rapid until a still higher altitude is attained.

On the other hand, carbon deposition does not take place with rapidity until the temperature is from 400° C. to 500° C. (say 840° F.), and this indicates that such deposition might depend upon reaction (12) between metallic iron and carbonic acid (CO_2), but it may also depend upon the reduction of iron oxide by carbon, as in reactions (4), (5) and (6). These are all endothermic—i.e., they absorb heat, while the reduction of iron oxide by carbonic oxide (CO) is exothermic—i.e., it creates heat. Reaction (4) begins to take place at about 400° C. (750° F.), so that at this temperature a supply of metallic iron is provided, and since carbonic acid (CO_2) is able, at this point, to oxidize metallic iron according to reaction (12), there may coexist all the factors necessary for any

reactions, since there may be present Fe_2O_3, Fe_3O_4, FeO, Fe, CO and CO_2. Two reactions occurring are (13) and (14),

$$(13)\ 2\ FeO+CO_2=Fe_2O_3+CO,$$
$$(14)\ 2\ Fe+3\ CO_2=Fe_2O_3+3\ CO,$$

the first creating heat and the second absorbing energy.

Experiments on carbon deposition were carried on by Laudig.* He passed blast-furnace gas over different ores, the gas containing about 7.5 per cent. CO_2, and 29 per cent. CO, the temperature being just above the melting point of zinc. The following list shows the results obtained, the figures being the weight of carbon deposited in per cent. of the weight of ore:

	Min.	Max.
Old range soft hematites	4.48	35.13
hard hematites	2.16	12.88
blue ores	1.56	4.72
brown ores	0.98	24.92
magnetites	nil	nil
Mesabis	10.20	36.40
Scale and cinder	0.08	0.74

It was assumed by Laudig that the reducibility and value of an ore depended upon two conditions:

(1) That it should be of such a character that carbon would be deposited throughout the mass;

(2) That it should not be too readily disintegrated or too much increased in volume by this action.

Cases were cited in tests of some of the Mesabi ores where the mass increased to four or five times its volume after exposure to the gas, thus explaining the choking and scaffolding encountered when smelting these fine varieties.

The reducibility of different ores was investigated by Wiborgh,† who concludes that it is dependent upon the density of the ore as measured by the specific gravity. Anything which increases the porosity assists the reduction, as, for instance, the roasting of a carbonate or a hydrate. By the same reasoning, hematite would be

*Trans. A. I. M. E., Vol. XXVI, p. 269. †Jerukontorets Annaler, Vol. LII, pp. 280-310.

easier to reduce in the blast furnace, because at very low temperatures it is converted into magnetite, losing a portion of its oxygen in so doing, and thus opening pores throughout the mass. Moreover, during this reaction carbon deposition may occur, while it is well known that very little carbon is deposited with magnetite.

Wiborgh shows that the degree of reduction is in proportion to the carbon deposition, the degree of reduction being the amount of reduced iron, expressed in per cent., of the total iron present. The results are tabulated herewith:

Number of Tests.	Percentage of Carbon Deposited.	Degree of Reduction.
6	0 to 1	70 to 82
6	1 to 2	83 to 86
4	2 to 3	85 to 86
2	4 to 6	90 to 93

In order to obtain a large proportion of deposited carbon, the temperature must be low and the ore porous. In the case of Bilbao ore, the deposited carbon in one case reached 12.23 per cent. It is urged by Wiborgh that Fe_6O_7 plays an important part in the blast furnace. He recognizes four oxides: Fe_2O_3, which he rates at 100 per cent. of oxidation; Fe_3O_4, rated at 88.9 per cent.; FeO, rated at 66.7 per cent., and Fe_6O_7, intermediate between the ferrous and magnetic oxides, with a rating of 77.8 per cent. of oxidation. Experiments seemed to show that it was Fe_6O_7, and not FeO, which formed during the experiments, and that this oxide was directly reduced in accordance with the following reaction:

$$Fe_6O_7 + 7\ CO = 6\ Fe + 7\ CO_2.$$

It is stipulated, however, that these conditions obtain when there is neither hydrogen nor deposited carbon, as these two agents tend to the formation of ferrous oxide. It would seem rash to assume that a furnace would run without the formation of hydrogen or without the presence of deposited carbon, and it may be better to cling to the old theory that FeO is the next stage after the magnetic oxide.

Much remains to be discovered in this field. Thus Laudig states

that there is almost no carbon deposition with magnetite, a fact which I have verified by experiment, and it is generally agreed that carbon deposition is essential to good reduction and fuel economy. Nevertheless, Cuban ore has been smelted at Steelton with less than a ton of coke per ton of iron and in a furnace only 65 ft. high, the practice being continued for a long time. This ore is mostly magnetite, in hard lumps, containing 10 per cent. silica, and from 0.25 to 0.50 per cent. sulphur, and on account of this latter impurity it was essential to maintain a good temperature, but this was done so successfully that the iron ran from a trace to .04 per cent. in sulphur.

It is possible that the volatilization of the sulphur in the upper part of the furnace may make the ore porous, but this explanation does not account for the easy reduction, because the sulphur is not distributed regularly throughout the ore, but is in separate crystals and masses, and under these conditions a content of less than half of one per cent. of sulphur is not enough to produce any great change in porosity. Moreover, this sulphur will not be completely distilled or acted upon in the upper zones of the furnace, where the relative reducibility is of great consequence. But even assuming that the volatilization of the sulphur renders the ore reducible, this merely proves that magnetite is not as hard to reduce as is generally supposed. It may be that an unusually hard ore like the Swedish magnetites will be less easily reduced than a porous mineral, but it is not logical to say that magnetic oxide is hard to reduce, simply because magnetic oxide usually occurs in hard and compact formations. The correct expression would be that compact ores are hard to reduce and that magnetites are usually of this character. Even this conclusion is open to dispute, for the Cuban ore above referred to is solid and in lumps, and yet gives as good a fuel ratio as would be expected from its silica content. Moreover, the Swedish magnetites themselves have been used in large quantities in Germany, and it is the experience in more than one works that no increase in fuel follows their use. I have been given the figures of two furnaces using about 40 per cent. of these ores, where the fuel for a whole campaign ran 1.05 tons of coke per ton of iron, although the burden carried only 42 per cent. of iron, and was in no measure self-fluxing. A large proportion of the charge was puddle cinder, which is not easy to reduce.

I have commented on the necessity of invoking something beside the oxidizing influence of carbonic acid upon iron to explain the beginning of the carbon impregnation, but the question is puzzling and difficult to investigate. The subject is of great importance, as it is known that carbonic oxide alone is unable to remove the last traces of oxygen from iron oxide, this office being performed by deposited carbon in the lower region of the blast furnace, and it is also known that carbon deposition ceases at about 600° C. and that carbonic acid (CO_2) then acts upon and dissolves carbon, so that in the lower and hotter portions of the furnace there is no carbon deposit except what is associated with the iron, waiting for a chance to unite with it as carbide.

Howe* has reviewed the work of Bell and others very thoroughly in respect to carbon impregnation, and concludes thus:

"The exact nature of the reactions is not known. Metals which like iron are reduced by carbonic oxide, but which unlike it are not oxidized by this gas or by carbonic acid, do not induce carbon deposition as far as known: this suggests that it is connected with the oxidation of iron by one or both of these gases by reactions like the following:

$$Fe+xCO=FeO_x+xC,$$
$$FeO_x+yCO=FeO_{x+y}+yC,$$

rather than to mere dissociation of carbonic oxide, thus:

$$2\,CO=C+CO_2,$$

which may be the resultant of either of these two reactions:"

$$FeO_x+yCO=FeO_{x-y}+yCO_2.$$
$$FeO_x+yCO=FeO_{x+y}+yC.$$

The chemical phenomena of a blast furnace have been represented graphically by Bell, and also in a book by Prof. Robt. H. Richards for use in the Massachusetts Institute of Technology, but no attempt has been made to show them with quantitative accuracy. I believe it is possible to map out the reactions, after assuming certain conditions. I have been assisted in this task by Mr. John

* *Metallurgy*, p. 122.

W. Dougherty, Superintendent of the Pennsylvania Steel Company, and the results are shown in Fig. II-D. The curves express quantitatively the relative amounts of each element or substance, for the conditions under consideration. The height is 90 feet, and information is given as to the temperature to be expected at different distances above the hearth. The conditions assumed are as follows:

Temperature at tuyeres, 1500° C.
Ore=60 per cent. Fe; no water.
Coke=87 per cent. C ; 1888 lbs. per ton of iron.
Stone=100 per cent. $CaCO_3$; 1010 lbs. per ton of iron.
Pig-iron=4 per cent. C; 1 per cent. Si.
Ratio of tunnel head gas by volume, 1 CO_2 to 1½ CO.
Temperature of tunnel head gases, 260° C.
Height of furnace, 90 feet.

It is assumed, upon the authority of Bell, that the carbon needed for the carburization of the pig-iron is deposited in the iron oxide, in the upper portion of the furnace, and that the amount so deposited is just sufficient for the work. An estimate is made of the cyanogen present. No data are given concerning silicon, sulphur, phosphorus and other elements, as their graphic representation on so small a scale would be a straight line. In the case of alumina, the amount is greater, but it has not been shown, as it undergoes no change and affects no constituent of the charge until it reaches the zone of fusion. The isothermal lines in a blast furnace are not horizontal, as they vary with the irregularities in the descent of the stock in different parts of the furnace, but it seemed unnecessary to show these complications.

From this diagram we learn the following:

At the tunnel head the ore (Fe_2O_3) is plunged into an atmosphere of CO=24 per cent., CO_2=16 per cent., N=60 per cent., and a temperature of about 260° C. (500° F.), and there is immediately a reduction of part of the ore to Fe_3O_4, this action increasing as the ore descends and reaches a higher temperature. By the time a depth of 10 feet is reached, all the Fe_2O_3 has been converted into Fe_3O_4 and the temperature is 450° C. (890° F.). Before this reduction is well under way, there begins the carbon deposition by which the gases react upon the ore and deposit carbon throughout

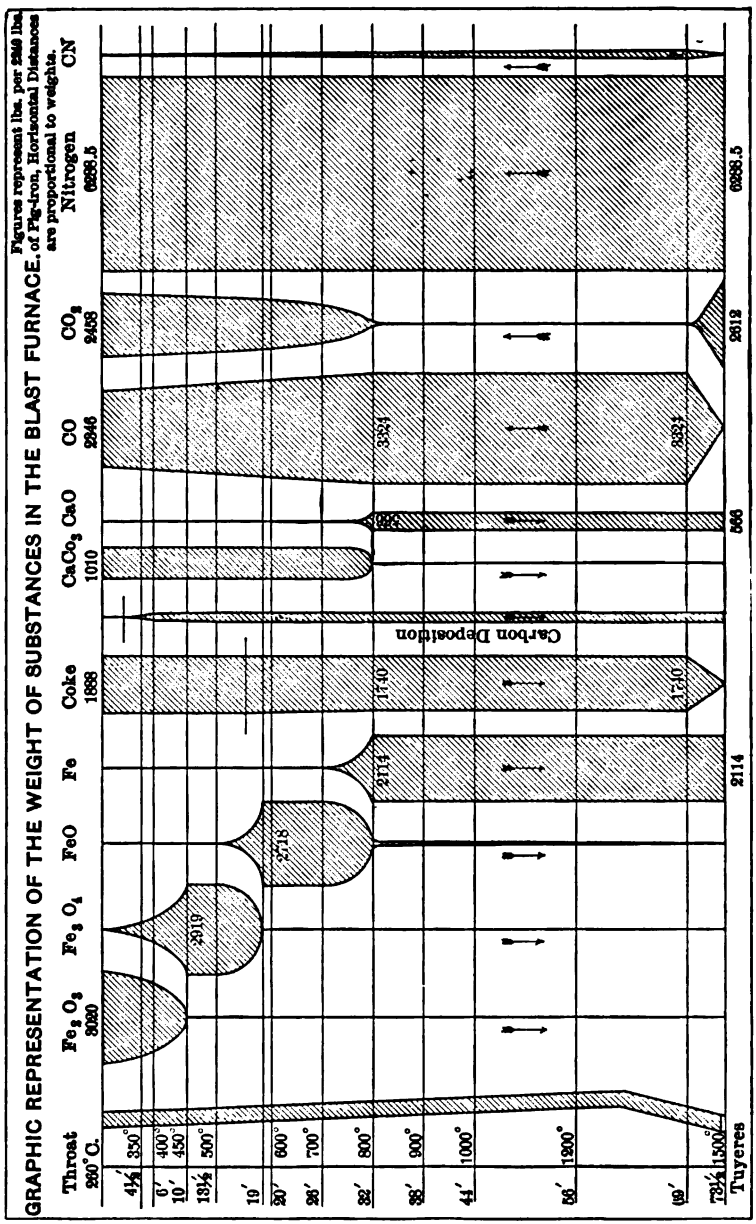

GRAPHIC REPRESENTATION OF THE WEIGHT OF SUBSTANCES IN THE BLAST FURNACE.
Figures represent lbs. per 2240 lbs. of Pig-iron, Horizontal Distances are proportional to weights.
Throat 260°C.
Fe_2O_3 2020
Fe_3O_4
FeO
Fe
Coke 1888
$CaCO_3$ 1010
CaO
CO 2246
CO_2 2458
Nitrogen 6298.5
CN
Carbon Deposition
Tuyeres
2114
1740
2324
2912
6298.5

FIG. II-D.

the pores of the oxide, and this carbon remains associated with the iron, finally furnishing the proportion needed for its conversion into pig-iron. This carbon deposition begins at a temperature of about 300° C. (570° F.), soon after the first stages of reduction are under way, rapidly increases until all the Fe_2O_3 is reduced to Fe_3O_4 at a temperature of about 450° C. (840° F.), and then continues at a slower rate until the Fe_3O_4 is all reduced to FeO at a temperature of about 600° C. (1110° F.). The mixture of carbon and metallic iron descends until the zone of fusion is reached, when the mixture is converted into iron carbide.

As above stated, the gases reduce the Fe_2O_3 and at a temperature of 450° C. the iron is nearly all present as Fe_3O_4. This descends unchanged until at 13½ feet it meets a temperature of 500° C. (930° F.), when it is strongly acted upon and converted into FeO, the transformation being complete when a temperature of about 580° C. (1080° F.) is reached at a depth of 19 feet. This FeO so formed, impregnated with deposited carbon, descends quite a distance unchanged until a temperature of 700° C. (1290° F.) is encountered at a depth of 26 feet, when the last atom of oxygen is taken by the carbonic oxide, and spongy iron begins to form. This reaction is completed when the temperature reaches 800° C. (1470° F.) at a depth of 32 feet.

The limestone comes down through the furnace until it encounters the temperature of 800° C. (1470° F.), at which the last of the FeO is reduced to spongy iron, when it is decomposed and the carbonic acid is driven off to rise through the stock, while caustic lime (CaO) descends to the zone of fusion to flux the silicious ingredients of the charge. The carbonic acid (CO_2) from the limestone plays an important and objectionable part in its passage to the tunnel head. At all temperatures above 550° C. (1020° F.) the following reaction occurs:

$$CO_2+C=2\ CO,$$

and as the limestone is not decomposed until a temperature of 800° C. is reached, it follows that during the passage of this carbonic acid from the point where it is made at a depth of 32 feet until it reaches a temperature of 550° C. (1020° F.) at a depth of about 17 feet, which is to say, during the travel of the gas through

a vertical distance of 15 feet, it is constantly reacting upon the coke. Experiments show that a quantity of carbonic acid equal to the amount liberated from the limestone is thus destroyed in the upper portions of the furnace, with the production of an equivalent amount of carbonic oxide (CO). The energy of this carbonic oxide may be subsequently utilized under boilers or in the stoves, but it is totally lost as far as the economy of the furnace itself is concerned.

It is not correct to say that all the carbonic acid from the stone is decomposed, for alongside of this amount is a certain quantity arising from the reaction between the ferrous oxide (FeO) and the carbonic oxide (CO), and there is no warrant for supposing that a molecule of gas derived from the stone has any history different from a molecule derived from the reduction of the ore; but it may be said, for the sake of simplicity, that the reactions in the upper portion of the furnace consist of the reduction of iron oxides (Fe_2O_3, Fe_3O_4, FeO) by carbonic oxide (CO) and the simultaneous oxidation of coke by the carbonic acid (CO_2) of the limestone. With the exception of this last reaction, and the formation of a small amount of carbon deposit, the coke charged at the top goes down through the furnace unchanged in quantity or condition until it reaches the immediate neighborhood of the tuyeres, the presence of so large a proportion of carbonic oxide rendering the oxidation of carbon out of the question.

Below the place where the last of the FeO is reduced, at a temperature of 800° C., at which point the limestone is decomposed, there are no reactions whatever occurring, and the whole history is one of heat absorption preparatory to the intense concentration of energy at the tuyeres. The temperature, therefore, rises steadily and regularly as the tuyeres are approached. This rise in temperature is shown upon the diagram as being uniform throughout the entire height of the furnace, which is not strictly true, for the bosh region is cooled by water, and, being at a high temperature, the chilling effect at this point must be more rapid than will be found higher up, where there is little radiation and no heat-absorbing reactions. There is another zone where the limestone is decomposed, and this portion would show a variation from a regular increase in temperature, while above that point considerable heat is absorbed by the union of carbonic acid from the stone with

coke ($CO_2+C=2\ CO$), and a considerable amount created by the reduction of the iron oxides by carbonic oxide (CO). Inasmuch as any attempt to equate these conditions would involve many assumptions, it may be as well to presuppose a uniform rate of progression.

The reactions in the neighborhood of the tuyeres differ from the reactions occurring higher up, on account of the facilitation of chemical action by the intense temperature. The blast is composed of nitrogen and oxygen; the nitrogen passes unchanged through the zone of fusion and the upper zones of reduction, and escapes in its original state and quantity with the tunnel head gases. A small and uncertain quantity combines with carbon to form cyanogen, which combines with potassium or sodium to form cyanides, but these are constantly undergoing decomposition in their passage upward through the ore, according to the reaction:

$$2\ KCN+3\ FeO=K_2O+2\ CO+3\ Fe+2\ N.$$

The oxygen, immediately upon entering, unites with glowing coke to form carbonic acid (CO_2), but by contact with other pieces of incandescent coke this is changed into carbonic oxide (CO), and from a distance of about four feet above the tuyeres to the point where limestone is decomposed and ferrous oxide reduced, there is no carbonic acid in the furnace, the entire atmosphere being composed of nitrogen and carbonic oxide (CO). The coke comes down through the furnace unchanged and unaffected in quality or quantity, save for the oxidation of a small amount by the carbonic acid (CO_2) from the limestone, until it reaches a point about four feet above the tuyeres, when it meets the carbonic acid (CO_2) formed at the tuyeres, and there then occurs the reaction:

$$CO_2+C=2\ CO.$$

At the same time other particles of incandescent carbon, possibly only a fraction of an inch away from where the foregoing reaction is taking place, are coming in contact with molecules of free oxygen from the blast, and there occurs the following reaction:

$$C+2\ O=CO_2,$$

the carbonic acid so formed being doomed to immediate destruction on its first meeting with the next molecule of incandescent carbon.

The final result of this combustion is the formation of carbonic oxide (CO) with no admixture of carbonic acid (CO_2), and this carbonic oxide rises in unchanging quantity to the point where it meets unreduced ferrous oxide (FeO). Here begins the formation of carbonic acid (CO_2) from both the reduction of the ore and the decomposition of the limestone, and in spite of the destruction of some carbonic acid (CO_2) by the coke with formation of carbonic

TABLE II-B.

Furnace Practice at Middlesborough and Pittsburg.

	Middlesborough.	Pittsburgh
General conditions—		
Height of furnace, feet	80	80
Cubic contents, feet	25,500	18,200
Per cent. of metallic iron in ore	39.0	59.0
Weekly product per 1000 feet cubic content, tons	21.57	128.00
Temperature of blast, degrees cent.	704	593
Temperature of tunnel head gases, degrees cent.	250	171
Ratio of CO to CO_2 in gases	2.11	2.35
Data per ton of pig iron—		
Coke, pounds	2239	1882
Limestone, pounds	1232	1011
Ore, pounds	5876	3613
Weight of blast, pounds	9761	7974
Weight of tunnel head gases, pounds	13,381	11,211
Slag, pounds	3136	1200
Calories used in the furnace per ton of pig iron—		
Reduction of Fe_2O_3	1,681,887	1,681,887
Reduction of metalloids in pig-iron	212,039	133,655
Dissociation of CO	73,152	74,168
Fusion of pig-iron	335,280	335,280
Evaporation of water in coke	13,970	4,216
Decomposition of water in blast	120,904	118,516
Expulsion of CO_2 from limestone	206,756	157,175
Reduction of this CO_2 to CO	214,579	177,190
Fusion of slag	782,320	299,212
Radiation, cooling water, etc.	494,792	296,145
Total absorbed in furnace	4,135,679	3,279,444
Calories in tunnel head gases per ton pig iron—		
Sensible heat	364,000	254,700
Potential as CO	3 810 000	3,137,000
Total in tunnel head gas	4 174.000	3,391,700
Summary per ton of pig iron—		
(a) Calories used in furnace (as above)	4,135,679	3,279,444
(b) Calories in tunnel head gases (as above)	4,174.000	3,391,700
Sum of (a) and (b)	8,309 679	6,671,144
(c) Less calories from blast included in (a)	738,632	626,872
Calorific power produced per ton of iron	7,571,047	6,044,272
Calorific power produced per ton of coke	7,574,400	7,196,000

oxide (CO) the proportion of carbonic acid (CO_2) in the gases increases all the way to the top.

All the figures relating to vertical distances must be changed for every variation in the height of different furnaces, and the temperature of the tunnel head gases is different at every furnace, while the horizontal measurements on the drawing must be made to accord with the furnace practice on coke, ore, etc., but it has been deemed worth while to solve one definite problem as an example of the method which seems applicable to all similar investigations.

SEC. III.—*The utilization and waste of heat.*—Any discussion of the distribution of heat in a blast furnace must base itself on the investigations of Sir Lowthian Bell. In one of his last con-

TABLE II-C.

Distribution of Energy at Middlesborough and Pittsburg.

Table II-B shows that the English coke was 5 per cent. better than American coke. Hence with the same coke, the fuel in Pittsburg would have been only 1788 lbs. per ton.

	Equivalent in Pounds of Coke.		Per cent. of total Calorific Value	
	English.	American.	English	American
Constant factors—				
Reduction of Fe_2O_3	452	452	20 2	25.2
Fusion of pig iron	90	90	4.0	5.0
Total	542	542	24.2	30.2
Factors beyond the control of the smelter—				
Reduction of the metalloids	58	36	2 6	2 0
Expulsion of CO_2, from limestone	56	41	2 5	2 3
Reduction of this CO_2 to CO	58	49	2 6	2.7
Fusion of slag	210	80	9.4	4.5
Total	382	206	17.1	11.5
Factors more or less under control—				
Dissociation of CO	20	20	0 9	1.1
Evaporation of water in coke	5	2	0.2	0.1
Decomposition of water in blast	34	33	1 5	1 8
Radiation, cooling water, etc	134	80	6.0	4.5
Total	193	135	8.6	7.5
Tunnel head gases—				
Sensible heat	99	68	4 4	3 8
Potential as CO	1023	837	45.7	47.0
Total	1122	905	50.1	50.8
Grand Total	2239	1788	100.0	100.0

tributions he compared* the working of a typical Pittsburg furnace with the practice in the Cleveland district in England. In Tables II-B and II-C the results are tabulated and expanded, so as to show the way the heat is utilized under two entirely different sets of conditions.

In Table II-C I have departed from his line of calculation in finding the equivalent amount of coke in the American furnace. The object of the investigation is to account for the larger amount of fuel used in England, and Bell sums up every way in which the lean and silicious ores of Cleveland increase the work to be done; but although he mentions that Connellsville coke contains more ash than the coke of Durham, he makes no allowance for this at all. The furnaceman cannot get calorific power out of this ash, and for this reason I believe that the calculation by Bell on the heat developed per unit of coke (p. 958 *loc. cit.*) is entirely misleading. The difference of 7.00 per cent. (not "7½ per cent.") is accounted for by the extra ash which the American coke contains, for Durham coke is given as 5 to 7½ per cent. in ash, while Connellsville will run at least 5 per cent. higher.

The composition of the gases from the Cleveland furnace is not given, but the ratio is recorded and the weight produced per ton of iron, and from these data I have calculated the composition. Bell views the gases simply as a vehicle of sensible heat, with the exception of the calorific power returned in the blast, but I believe it more correct to calculate *all* the potential energy in the coke and find how much is accounted for, either as potential or chemical energy, or as sensible heat. Bell did this in previous writings and showed that in one case 74 per cent. of the heating power of the fuel was employed in useful work, but this counted the energy developed in boilers and hot stoves. I believe it is better to keep this energy separate under the name of "potential heat in gas," as the economical use of such gas is a problem entirely distinct from the metallurgy of a blast furnace. Table II-D gives the total heat developed in the furnace and the distribution of this heat.

The potential heat includes all the energy of the escaping gases, except the sensible heat. It appears later in four places:

* *Trans. A. I. M. E.*, Vol. XIX, p. 957.

(1) Heat utilized in stoves in heating the blast.

(2) Heat utilized in boilers in making steam.

(3) Heat lost in ovens by incomplete combustion, in the stack gases, and by radiation.

TABLE II-D.

General Equation of the Blast Furnace.

	Middlesborough.	Pittsburg.
Per ton of pig iron—		
Calories from formation of CO_2	2,427,000	1,982,000
Calories from formation of CO	1,336,000	1,025,000
Calories potential in gas as CO	3,810,000	3,137,000
Total per ton of iron	7,573,000	6,144,000
Per ton of coke—		
Calories from formation of CO_2	2,428,000	2,360,000
Calories from formation of CO	1,342,000	1,220,000
Calories potential in gas as CO	3,812,000	3,735,000
Total per ton of coke	7,582,000	7,315,000
Distribution by per cent. of total energy—		
Per cent. from formation of CO_2	32.1	32.2
Per cent. from formation of CO	17.6	16.7
Per cent. potential in gas as CO	50.3	51.1
Total	100.0	100.0

(4) Heat lost at boilers by incomplete combustion, in the stack gases, and by radiation.

It would be possible to verify the conclusions if the exact calorific value of the coke were known, but this is not given in either case. Bell assumes that Durham coke contains 10 per cent. of earthy and volatile materials, but some of this volatile matter is hydrogen, which appears as potential heat in the gases. It is probable that the heat value of Durham coke is about 7400 calories per kilogram, or say 7,500,000 calories per ton. The coke of Connellsville will probably give about 7,120,000 calories per ton. The figures given in Table II-D, as found by theoretical calculations, show a value for Durham coke of 7,582,000 calories, being about 1 per cent. greater than the foregoing assumption, and for Connellsville 7,315,000 calories, being about 3 per cent. more, while in Table II-B a somewhat different method gave 7,574,000 calories for Durham and 7,196,000 calories for Connellsville. This is a sufficiently close approximation, considering the inaccuracy of the data.

The Middlesborough and Pittsburg furnaces represent two extremes of good practice; one with lean ores and slow-running, and the other with rich ores and fast-running, and from Tables II-C and II-D the following conclusions may be drawn:

(1) Of all the heat energy contained in the coke charged in a blast furnace, one-half goes away in the tunnel head gases, part as sensible heat, but most of it as unburned CO.

(2) The proportion of heat so lost is about the same whether the furnace is working on lean ores with a high consumption of fuel or on rich ores with a low fuel ratio.

(3) The other half of the energy is used in reducing the iron ore, in melting the iron and slag, in losses from conduction and radiation, and in minor chemical reactions.

(4) The proportion of the total energy used for each one of these items depends upon the special conditions; as, for instance, the proportion needed for the reduction of CO_2 and the proportion needed for the melting of the slag both depend on the amount of limestone needed, and this, in turn, depends on the impurities in ore and fuel. In the reduction of the ore and the fusion of the pig-iron, both of which take a given amount of heat, the proportion which this given amount bears to the total will depend solely upon what the total is, being greater with a small fuel ratio.

(5) The proportion lost in radiation and through the cooling water will decrease as the output of the furnace is increased, either by the use of rich ores or by rapid driving, or both.

(6) The reduction of the ore calls for between 20 and 25 per cent. of all the energy delivered to the furnace.

(7) The fusion of the pig-iron requires from 4 to 5 per cent.

(8) The fusion of the slag requires from 4.5 to 9.4 per cent., increasing with the amount of impurities and the quantity of stone.

(9) The heat lost by radiation and in cooling water varies from 4.5 to 6.0 per cent., decreasing with a larger output of pig-iron.

(10) The reduction of the metalloids, the expulsion of CO_2 from limestone, and the reduction of this CO_2 to CO, each requires from 2 to 3 per cent.

(11) The dissociation of CO, and the decomposition of water in the blast, each calls for from 1 to 2 per cent., while the evaporation of the water in the coke takes a small fraction of 1 per cent.

(12) Some factors are beyond the control of the smelter, as for in-

stance, all those depending on the limestone, this being determined by the impurities to be fluxed. In the American furnace the factors beyond the control of the smelter required only 206 pounds of coke, while in the English furnaces 382 pounds were needed, a difference of 176 pounds. Inasmuch as fifty per cent. of all the energy is lost in the escaping gases, these factors alone account for an extra 352 pounds of fuel in the English furnace.

(13) The factors which are more or less under control are practically the same in both cases, giving a total of 7.5 per cent. in Pittsburg and 8.6 per cent. in Cleveland.

(14) The loss in the tunnel head gases is the only great item presenting any hope for future economies. In the Cleveland practice the ratio of CO to CO_2 was 2.11. In Pittsburg it was 2.35. It has been stated by Bell that a ratio better than 2 to 1 can hardly be hoped for, but this is a mistake, as many furnaces can show better results. A ratio of 1.5 to 1 can be obtained, while the future may see even greater economy.

SEC. IIm.—*Tunnel head gases.*—At every blast furnace the tunnel head gases are sufficient to heat the stoves and raise steam for the blowing engine and the pumps, while at many plants there is a surplus above these needs which is used to generate steam power or electric energy. It is clear that any right system of bookkeeping will give credit to the furnace for this power at a fair price, which, in a plant equipped with proper boilers and engines, will amount to about 25 cents per ton of iron. Modern progress tends to reduce the amount of fuel per ton of iron, either by more skilful management or by hotter blast, or by concentration of the ore, or by the refrigeration of the air, so the question arises whether a reduction in fuel may not seriously detract both from the volume and the heat value of the gas, with the result that a furnace might no longer be self-supporting and that in place of a credit for surplus power there would be a debit for extra coal.

The investigation of this question is simplified by taking as a basis a ton of coke and not a ton of iron, for the capacity of a furnace is limited not so much by the amount of ore and stone as by the amount of fuel. Given a furnace using 2500 pounds of coke per ton of iron, and let the working conditions be bettered so that only 2000 pounds are needed, and the product will be increased 25 per cent. The blowing engine is capable of delivering just so

many cubic feet of air, which will burn just so many pounds of coke, so that any reduction in the amount of fuel per ton will be followed by a corresponding increase in the tons of iron made, and it follows that the furnace will burn the same quantity of coke in one hour or in one minute as before. Laying aside all question of a better carbon ratio, the engine will deliver the same

TABLE II-E.

Method of Calculating the Composition and Value of Tunnel Head Gas.

Assumptions for ton of pig iron.	Carbon; lbs.	Oxygen; lbs.
Coke, 2000 lbs., 87 per cent. carbon	1740	.....
Stone, 1000 lbs., 94 per cent. $CaCO_3$; (only CO_2 enters gas)	113	301
Ore=Fe_2O_3; one ton pig=95 per cent. Fe=2128 lbs. Fe		912
Moisture, 3.6 grains per cu. ft.; 108,000 cu. ft. air=55.7 lbs. H_2O	.....	49
Total carbon in coke and stone	1853	.....
Carbon in pig iron=3.75 per cent.	84	.....
Carbon and oxygen in stock, available for gas	1769	1262
Carbon ratio, assumed to be 1.7	.....	.....
C as CO_2=1769×$\frac{12}{33}$=655 lbs.=2402 lbs. CO_2	655	1747
C as CO=1769×$\frac{17}{33}$=1114 lbs.=2599 lbs. CO	1114	1485
Total carbon and oxygen in CO_2 and CO	1769	3232
Available oxygen in ore and stone, as above	.....	1262
Oxygen derived from blast	.....	1970

	Volume; cu. ft.	Per cent.
Volume of oxygen from air, 1970÷0.089	22,130	.....
Nitrogen with this oxygen, 22,130×3.785	83,760	.....
Assuming 0.3 per cent. free oxygen in gas, the nitrogen with this free oxygen will be about	1590	.....
Total nitrogen in gas	85,350	60.6
CO_2 in gas=2402÷0.123	19,510	13.9
CO in gas=2599÷0.078	33,320	23.7
Free oxygen, assumed to be 0.3 per cent.	420	0.3
Free hydrogen, assumed to be 1.5 per cent.	2110	1.5
Total gas per ton of iron	140,710	100.0
Air per ton of iron, 85,350÷0.791 (air=79.1 per cent. N)	107,900	.....
Air per ton of coke, 107,900×$\frac{2000}{1740}$	120,850	.....
Gas per ton of coke, 140,710×$\frac{2000}{1740}$	157,600	.....

	B. T. U.
Calorific value of gas per cu. ft.	86.2
Calorific value of gas per ton of coke, 157,600×86.2	13,585,000
Sensible heat of gas from one ton of coke, gas = 500° F.; 157,600×0.0303×500	1,599,600
Total energy in gas at 500° F	15,184,600
Calorific value of one ton of coke	28,538,000
Sensible heat per ton of coke, blast=1100° F.; 120,850×0.022×1100	2,924,600
Total heat entering furnace per ton of coke	31,462,600
Per cent. of energy in gas, 15,184,600÷31,462,600	48.26

number of cubic feet of air per minute and the same cubic feet of air per ton of coke, while the volume of tunnel head gas will likewise be the same as before per minute and per ton of coke. If the gas were of equal quality in both cases, the amount needed for stoves and engines and the amount available for surplus power would not be greatly changed by a reduction in the coke consumption.

The discussion of the matter is taken up in the following order:

(1) Calculation on the volume and heat value of the gas.
(2) Rough methods of corroborating these calculations.
(3) Amount of steam in gas.
(4) Energy needed to heat the blast.
(5) Results of burning gas under boilers.
(6) Production of power in steam engines.
(7) Production of power in gas engines.

SEC. IIn.—*Volume and value of the tunnel head gas.*—Table II-E gives the method of calculating the composition and volume of tunnel head gas under certain assumed conditions, while Table II-F arbitrarily assumes several different sets of furnace conditions, so as to constitute a series for comparing the effect of different factors: thus two columns are alike in amount of fuel, stone, and atmospheric moisture, but different in carbon ratio; another two have the same fuel, stone and carbon ratio, but differ in moisture. The effect of an increase in the amount of limestone is difficult to calculate. In E and F two extreme suppositions have been made: in E it is assumed that all the carbonic acid in the additional weight of stone is driven off unchanged; in F it is assumed that this gas reacts upon the coke and is all converted into carbonic oxide. Neither of these extremes is true, but a portion of the carbonic acid would pass off unaltered and a portion would react upon the carbon. The column with 1700 pounds of coke assumes conditions similar to those given by Gayley in his experiments on refrigeration; while the two columns showing 3300 pounds of fuel per ton of iron illustrate practice at furnaces where the ore carries 20 per cent. of silica, 1.5 per cent. of sulphur after roasting, and only 42 per cent. of iron. Viewing each set of conditions as a separate problem, the volume and calorific value of the tunnel head gases have been worked out. It is assumed that the gas contains 1.5 per

TABLE II-F.

Composition and Value of Tunnel Head Gas.

Assumptions: Coke=87 per cent. carbon. Stone=94 per cent. $CaCO_3$. 1 cu. ft. CO=345 B. T. U. 1 cu. ft. H=294 B. T. U. 1 lb. coke=12,740 B. T. U. 1 ton coke=28,538,000 B. T. U. Sp. heat of gas=0.0203 B. T. U. per cu. ft. It is assumed that the oxygen in CaO, MgO, Al_2O_3, etc., is not set free, all oxygen being derived from the air, the ore, the carbonic acid of the stone, and the moisture in the blast. On a moist summer day the air holds about 6.0 grains of water per cu. ft. On a cold winter day it holds 1.7 grains or less. The average for the year is about 3.6 grains.

	Per ton of iron; lbs.		Carbon ratio in gas.	Moisture in blast; grains per cu. ft.	Composition by volume; per cent.					Per ton of iron; cu. ft.		Ratio of gas to air; by volume.	Per ton of coke; cu. ft.	
	Coke.	Stone.			CO_2	CO	H	O	N	Air.	Gas.		Air.	Gas.
A	1700	1000	1.25	1.7	16.93	21.22	1.50	0.30	60.05	89,770	118,300	1.329	118,310	155,910
B	2000	1000	1.70	3.6	14.08	23.98	1.50	0.30	60.14	105,700	139,090	1.316	118,390	155,780
C	2200	1000	2.20	3.6	11.97	26.42	1.50	0.30	59.81	114,480	151,470	1.323	116,540	154,201
D	2400	1000	3.00	3.6	9.77	29.29	1.50	0.30	59.14	121,190	162,260	1.339	113,110	151,440
E	2400	2000*	2.47	3.6	11.61	28.72	1.50	0.30	57.87	121,190	165,900	1.369	113,290	154,840
F	2400	2000†	3.22	3.6	9.98	32.08	1.50	0.30	56.14	112,740	159,090	1.411	105,400	148,480
G	2600	1000	3.70	3.6	8.33	30.87	1.50	0.30	59.00	130,500	175,050	1.341	112,430	150,800
H	2200	1000	2.20	6.0	12.11	26.68	1.50	0.30	59.41	112,550	149,960	1.332	114,580	152,660
I	2200	1000‡	2.20	6.0	12.27	27.01	1.50	0.30	58.92	111,510	149,760	1.343	113,520	152,460
K	2200	1000	2.20	1.7	11.90	26.20	1.50	0.30	60.10	115,000	152,730	1.328	117,070	155,480
L	2200	1000	1.70	1.7	13.54	23.02	1.50	0.30	61.64	123,950	159,140	1.284	126,190	162,010
M	2200	1000	1.70	6.0	13.80	23.46	1.50	0.30	60.94	120,300	156,200	1.298	122,460	159,010
N	3300	1800	5.00	1.7	6.55	32.75	1.50	0.30	58.90	169,610	227,880	1.344	115,130	154,680
O	3300	1800	5.00	6.0	6.67	33.33	1.50	0.30	58.20	164,650	223,870	1.360	111,760	151,960

	Sensible heat of blast at 1100° F. per ton of coke. B. T. U.	Calorific value of gas per cu. ft. B. T. U.	Energy in gas per ton of coke. B. T. U.			Total energy of one ton of coke plus the heat in blast at 1100° F.	Per cent. of total energy in the gas at 500° F.
			Calorific value.	Sensible heat at 500° F.	Total energy at 500° F.		
A	2,863,100	77.62	12,101,700	1,582,500	13,684,200	31,401,100	43.58
B	2,865,000	87.14	13,574,700	1,581,200	15,155,900	31,403,000	48.26
C	2,820,300	95.56	14,735,400	1,565,100	16,300,500	31,358,300	51.98
D	2,737,300	105.46	15,970,900	1,537,100	17,508,000	31,275,300	55.98
E	2,741,600	103.49	16,024,400	1,571,600	17,596,000	31,279,600	56.13
F	2,550,700	115.09	17,088,600	1,507,100	18,595,700	31,088,700	59.81
G	2,720,900	110.91	16,725,200	1,530,600	18,255,800	31,258,900	58.40
H	2,772,800	96.46	14,725,600	1,549,500	16,275,100	31,310,800	51.98
I	2,747,200	97.59	14,878,600	1,547,500	16,426,100	31,285,200	52.50
K	2,833,100	94.80	14,739,500	1,578,100	16,317,600	31,371,100	52.01
L	3,053,800	83.83	13,581,300	1,644,400	15,225,700	31,591,800	48.20
M	2,963,500	85.35	13,571,500	1,614,000	15,185,500	31,501,500	48.26
N	2,786,100	117.40	18,159,400	1,570,000	19,729,400	31,324,100	62.98
O	2,704,600	119.40	18,144,000	1,542,400	19,686,400	31,242,600	63.01

* The CO_2 from the extra 1000 pounds of stone is assumed to escape as CO_2.

† The CO_2 from the extra 1000 pounds of stone is assumed to be converted into CO by the coke.

‡ In this case the stone is assumed to be one-fourth M_gCO_3.

cent. of free hydrogen, and 0.3 per cent. of free oxygen, the hydrogen coming partly from the volatile matters of the coke and partly from the decomposition of moisture in the atmosphere. In a humid summer day this moisture alone would be sufficient to give 1.5 per cent. of hydrogen in the gas.

The results found by calculation agree closely with the analyses of actual gases, as shown by the following averages of gas samples, each sample being collected throughout the space of one hour or more. In each case a comparison is made between the actual figures and the line in the foregoing table where the carbon ratio and the working conditions are about the same. The figures given for a carbon ratio of 1.24 are taken from Gayley's paper on dry blast; the other analyses are all from Steelton furnaces.

	Ratio.	CO_2	CO	N+O+H
Actual 5 tests	2.97	9.9	29.5	60.6
Table	3.00	9.8	29.3	60.9
Actual 4 tests	2.19	12.1	26.6	61.4
Table	2.20	12.0	26.4	61.6
Actual 2 tests	1.71	13.6	23.2	63.2
Table	1.70	13.8	23.5	62.7
Actual	1.24	16.0	19.9	64.1
Table	1.25	16.9	21.2	61.9

The table shows that a wasteful furnace using high fuel and having a high carbon ratio requires more air per ton of iron and delivers more gas, but uses about the same air and delivers about the same volume of gas per ton of coke burned. An increase in the amount of limestone increases in slight degree the volume of gas, but the quality of the gas depends altogether upon how much of the carbonic acid is converted into carbonic oxide. It is shown also that it is of little moment, as far as the gas is concerned, whether or not the stone contains magnesia. An increase or decrease in the amount of moisture in the air has little influence upon the amount or composition of the gas so far as theoretical calculation is concerned, but this has no relation to the well-known fact that with dry air less fuel is needed and a better carbon ratio obtained.

SEC. 110.—*Rough estimation of the volume of the gas.*—The volume of gas can be roughly calculated by simple means. The air entering the tuyeres contains 79 per cent. of nitrogen by volume, while the tunnel head gas carries about 60 per cent. The specific gravity of the gas is almost exactly the same as that of air, and as

no nitrogen is lost or gained in the interior of the furnace the volume of gas made from 100,000 cubic feet of air will be

$$\frac{100{,}000 \times 79}{60} = 132{,}000 \text{ cubic feet.}$$

In other words, the volume of gas will be about one-third more than the volume of air supplied.

SEC. IIp.—*Rough estimate of the heat value of the gas.*—The percentage of nitrogen in the gas runs about 60 per cent., and there are from one to two per cent. of hydrogen and some free oxygen, both the hydrogen and oxygen being often rated as nitrogen by the chemist. The carbonic acid (CO_2) and the carbonic oxide (CO) sum up about 38 or 39 per cent., and this total is fairly constant even under wide variations in furnace conditions. If, therefore, we have a carbon ratio of 2, the CO_2 must be about 12.8 per cent. and the CO=25.7 per cent. If the ratio is 3 the CO_2=9.6 and CO=28.9. If the ratio is 4 the CO_2=7.7 and CO=30.8. Any wide deviation from these figures will usually arise from errors in sampling or determinations, or from the presence of unusual amounts of free hydrogen. Abnormal results may be obtained from samples taken over a short period of time, for the gas should be drawn from the furnace in a regular stream during at least one hour, to avoid temporary irregularities. Assuming the value of carbonic oxide to be 3070 cals. per cubic metre=345 B.t.u. per cubic foot, the value of the gas as above given for a carbon ratio of 2 would be 88.7 B.t.u. per cubic foot; with a ratio of 3 it would be 99.7 B.t.u. and with a ratio of 4, 106.3 B.t.u., so that a reduction from a ratio of 3 to a ratio of 2 means a reduction of 11 per cent. in the calorific value of the gas per unit of volume.

SEC. IIq.—*Steam in gas.*—Steam is always present in tunnel head gas, but is generally neglected by the chemist, as special arrangements must be made for its determination. When the ore and coke are dry the gas will carry about 2 per cent. of steam by volume, but when they both carry 10 per cent. by weight of water, as sometimes happens in wet weather, the gas will contain 8 per cent. and the total volume produced will be 8 per cent. more than shown by the table. Gas with this amount of moisture burns much less readily under the boilers, and there is a loss of energy from

unburned combustible as well as from the sensible heat carried away by the inert steam in the products of combustion.

SEC. IIr.—*Heating the blast.*—The energy present in the tunnel head gases is used for two purposes: (1) heating the blast; (2) producing power. It has been shown in the foregoing calculations that a normal furnace, using from 1800 to 2300 pounds of coke per ton of iron, requires from 115,000 to 125,000 cubic feet of air per ton of coke burned, the exact volume depending on the carbon ratio and other working conditions. Assuming 120,000 cubic feet as a basis and that the air is heated to 1100° F., at which temperature its specific heat is .022 B.t.u. per cu. ft., the blast for one ton of coke will require

$$120{,}000 \times 0.022 \times 1100 = 2{,}904{,}000 \text{ B.t.u.}$$

Assuming that the hot stoves give an efficiency of 50 per cent., the energy in the gas sent to these stoves must amount to 5,808,000 B.t.u. for each ton of coke burned. The total energy contained in the tunnel head gases under usual conditions amounts to about 16,000,000 B.t.u. per ton of coke burned, so that under the above assumptions the stoves require a little over one-third of all the gas. This agrees with the estimates usually made by furnacemen.

SEC. IIs.—*Combustion of the gas under boilers.*—The composition of tunnel head gas varies widely, but the composition of the products of combustion obtained by burning different gases is practically the same without regard to these variations. Taking C in Table II-F as a normal gas and A and O as extreme cases, the gases resulting from their perfect combustion will be as shown in Table II-G, when just the amount of air is used that is theoretically necessary:

TABLE II-G.

Products of Combustion of Tunnel Head Gas.

	Composition of gas: by volume.					Composition of products of combustion: by volume.	
	CO_2	CO	H	O	N	CO_2	N
C	11.97	26.42	1.50	0.30	59.81	25.64	74.36
A	16.93	21.22	1.50	0.30	60.05	27.05	72.95
O	6.67	33.33	1.50	0.30	58.20	24.58	75.42

In burning soft coal, no matter whether it be burned directly in a shallow fire or whether it be first put through a producer and the gas afterward burned in a furnace, the ultimate products of combustion with no excess of air contain CO_2=18 per cent., N=82 per cent. The products of combustion from blast-furnace gas are much higher than this in CO_2 and lower in N, because the ore supplies oxygen without nitrogen, an unusual condition in ordinary processes of combustion. In most operations where fuel is burned, twice the amount of air must be supplied that is theoretically necessary in order to insure the complete burning of all the combustible components in the gas, and the loss of heat arising from this excess is much less than the loss arising from the escape of unburned combustible when the excess of air is too small. Following is the result of burning 100 cubic feet of gas with twice the theoretical quantity of air:

100 cu. ft. gas+130.3 cu. ft. air=214.9 cu. ft. products of combustion of the following composition:

CO_2=17.87 per cent., O=6.36 per cent., N=75.77 per cent.

The specific heat of gases varies with the temperature. In this case the whole mass of products have a specific heat of .0198 B.t.u. per cu. ft. at a temperature of 32° F., .0213 at 600° F. and .0228 at 1200° F. The specific heat of the excess air contained in these products is somewhat less than the average, being only .0192 at 32° F., but for practical purposes these variations may be ignored, and in calculating the waste of heat in gases escaping at moderate temperatures from boilers or stoves the specific heat may be taken at .022 B.t.u. per cubic foot, and if twice the necessary amount of air has been used so that the excess air constitutes 30 per cent. of all the products of combustion, it may be assumed that this air carries away 30 per cent. of the wasted heat. The gas C has a calorific value of 95.56 B.t.u. per cubic foot, but counting its sensible heat at 500° F. its value is 105.7 B.t.u. The value of 100 cu. ft. will be 10,570 B.t.u., and the heat lost in the products of combustion under different conditions are as shown in Table II-H.

The temperature of gases escaping from boilers ranges from 500° F. with fairly good practice to 1100° F. or more with bad practice. The loss of heat due to this cause is 22 per cent. of the total

value of the fuel under good practice to 49 per cent. or more under bad practice. One-third of this loss is due to the excess air, it being assumed that twice the necessary amount is used. The dif-

TABLE II-H.

Loss of Heat in Products of Combustion.

Temperature of waste gas. Degrees Fahr.	Heat loss; per cent. of fuel value.		Heat utilized; per cent. of fuel value.	Proportionate fuel needed.
	By excess air.	Total.		
500	7	22	78	100
800	11	36	64	122
1100	15	49	51	153
1400	19	63	37	211

ference between good and bad practice is 27 per cent. or just about one-quarter of the total value of the fuel. A boiler forced beyond its capacity so that the escaping gases are at a temperature of 1100° F. will need 53 per cent. more fuel than one where the gases are at 500° F. If the stack is red hot, as is sometimes the case, the boiler is using twice as much fuel as is needed under good conditions.

SEC. IIt.—*Use of tunnel head gas for the production of power by steam engines.*—It has been shown that a boiler under good conditions loses in the stack gases from 20 to 30 per cent. of all the energy in the fuel. There are other losses, as, for instance, by radiation, so that the average modern boiler plant running on furnace gas will probably not give over 60 per cent. efficiency. It has also been proven that the tunnel head gas from one ton of coke contains energy equivalent to 16,000,000 B.t.u. and that the stoves require 5,000,000 B.t.u., leaving 11,000,000 B.t.u. for the production of power. In a furnace using 400 tons of coke per day the amount available would be 4,400,000,000 B.t.u. per day. The pumps and hoisting engines require, say, 300 B.h.-p., or a total of 240,000,000 B.t.u. in the form of steam. Assuming 60 per cent. efficiency in the boiler plant, this represents 400,000,000 B.t.u. in the gas, which, being subtracted from 4,400,000,000, leaves 4,000,000,000 B.t.u. for the blowing engine and other purposes. A good engine requires about 9-16 of one boiler horse-power to produce an indicated horse-

power, or 450,000 B.t.u. per 24 hours. Assuming 60 per cent. efficiency in the boiler plant, each engine horse-power calls for 450,000÷0.6=750,000 B.t.u. per 24 hours, and the foregoing figure of 4,000,000,000 B.t.u. represents 5330 horse-power. Of this amount the blowing engine will require 3000 horse-power, leaving a surplus of 2330 horse-power for other purposes.

SEC. IIu.—*Use of tunnel head gas for the production of power by gas engines.*—It has just been shown that a 400-ton blast furnace, after supplying its stoves, pumps, and hoisting engines, has 4,000,000,000 B.t.u. per day available for the blowing engines and for surplus. This is true for a steam equipment, but the figure is somewhat less for gas engines, since in the latter case the sensible heat of the gas is of no value. This sensible heat is 1,500,000 out of a total of 16,000,000 B.t.u., so that by proportion the amount available for the gas engine plant will be 3,600,000,000 per day. Assuming that a gas engine will produce one horse-power from 360,000 B.t.u. per day, there will be a total of 10,000 horse-power, or a surplus of 7000 horse-power after the blowing engine is supplied.

SEC. IIv.—*General conclusions on the production of power from tunnel head gas.*—The energy in one ton of coke is about 28,500,000 B.t.u. The blast when heated to 1100° F. carries about 2,500,000 B.t.u. or 8 per cent. additional, making a total of 31,000,000 B.t.u. entering the furnace per ton of coke. Half of this energy is dissipated in the furnace, while the other half is contained in the tunnel head gas. The calorific value of the gas from a ton of coke is about 14,500,000 B.t.u., but the sensible heat at a temperature of 500° F. is 1,500,000 B.t.u., making a total of 16,000,000 B.t.u. or one-half the amount entering the furnace. Thus out of every 100 units of energy contained in the coke and the blast, 50 units come out in the gas, but of these 50 units it is necessary to send 17 units to the stoves, in order that 8 units may appear in the blast, it being assumed that the stoves have an efficiency of 50 per cent. This leaves 33 units for the production of power. If gas engines are used the sensible heat will not be available and only 30 units will be of use. In either case the amount is sufficient, when economical engines are used, to drive the blowing engine and pumps, and have a considerable surplus. In the case of a furnace using 400 tons of coke per day, and equipped with

steam machinery, this surplus should be about 2000 indicated horse-power. With gas engines it should be 7000 horse-power. The above figures are true only for usual operating conditions, for with an unusually low fuel ratio there will be less surplus, while with abnormally high coke consumption the surplus will be greater, but the variation is less than might be expected, as the calculations are based on a ton of coke charged and not a ton of iron smelted.

SEC. IIw.—*Composition of pig-iron.*—Carbon: The metal produced by the blast furnace is not pure iron, for while it is in contact with white-hot coke it absorbs a certain proportion of carbon. The amount absorbed is quite constant, seldom being less than 3.25, nor more than 4.25 per cent. When the iron is in a melted state all of this carbon is chemically combined with the iron, but as the metal cools there is a tendency for it to separate as graphite. This separation requires an appreciable time and can be prevented by sudden cooling. If a small quantity of liquid iron be chilled in a stream of water or an iron mold, almost all the carbon will remain combined, and the metal be hard and brittle. If, on the other hand, a large mass of iron be poured in sand and covered so as to cool slowly, the separation of carbon will go on for a long time, and the resulting metal will be soft and tough and a fractured surface will exhibit loose flakes of graphite.

Silicon: Pig-iron contains silicon from the reduction of silica; $SiO_2+2C=Si+2CO$. This silica is always present in iron ore, in the ash of the coke and in the limestone. It is difficult to reduce, and if the temperature of the furnace is low the iron will contain only about one-half of one per cent. of silicon, while if the furnace is hot the reducing action of the coke is more powerful and the iron may contain four or five per cent.; while under special conditions an alloy called ferro-silicon may be produced with over ten per cent. Silicon tends to drive carbon out of combination into the free or graphitic state, so that a pig rich in silicon will usually have an open fracture, but this iron will often contain less carbon than ordinary iron, as the high silicon prevents the absorption of the usual proportion.

Phosphorus: The amount of phosphorus present in pig-iron depends upon the materials used, for whatever of this element exists in the ore, in the coke, or in the limestone will be found in the metal. In pig-iron intended for foundry work the phosphorus may

vary through wide limits, contents as high as three per cent. being sometimes used in admixture. Such a large amount gives a brittle iron, but it gives increased fluidity, which is advantageous in making complicated castings. For ordinary castings a content of about one-half of one per cent. is usual. For the making of steel by the acid Bessemer process, as used throughout America, the iron must not contain over one-tenth of one per cent. of phosphorus. Inasmuch as nearly two tons of ore are used for a ton of pig-iron, and as the coke and limestone both contribute phosphorus, it will be seen that suitable "Bessemer ore" should have less than one-twentieth of one per cent. of this element. The steel maker classifies all the ores of the world by the second and third place decimal of one per cent. of phosphorus.

Sulphur: Iron ores as a rule are low in sulphur, but coke always contains a considerable amount, one-half of one per cent. being very low and one and one-half per cent. quite common. If the blast furnace is working well with a good slag and a high temperature, almost all of this sulphur will unite with the lime and be carried off in the cinder and the iron will contain less than one-twentieth of one per cent. of sulphur; but if the furnace is cold and the slag not sufficiently basic, the metal may contain over half of one per cent. Sulphur tends to hold carbon in combination, and therefore iron containing a high percentage is usually hard and brittle, this being especially the case when the percentage of silicon is low, a condition often existing, as a cold furnace is likely to produce high sulphur and low silicon.

Manganese: Iron ores generally contain more or less manganese, but usually in small proportion. Moreover, it is not all reduced in the furnace, some of it passing away in the slag. The ordinary pig-iron of commerce carries less than one per cent., but two per cent. is not uncommon. In the manufacture of steel a large amount of spiegel iron is used, by which is meant an iron containing from 10 to 26 per cent. of manganese. Ferro-manganese is also used containing up to 80 per cent. Manganese causes the carbon to remain in combination so that spiegel iron is hard and brittle. The total content of carbon is higher in manganiferous irons, being often up to 7 per cent. in 80 per cent. ferro-manganese.

Other Elements: Many other elements are often found. Copper is easily reduced in the furnace, and some irons contain over one

per cent., with no effect upon the physical qualities. Chromium is also easily reduced, but is uncommon, and, as it causes brittleness, the pig-iron is unmarketable. Titanium is partly reduced, and

TABLE II-I.

Composition of Various Pig-Irons and Spiegels.

No. of Sample.	Chemical Composition, Per Cent.							Kind of Iron.	Authority.
	Fe	Graphite.	Comb. Carb.	Si	P	S	Mn		
1	92.87	3.52	0.13	2.44	1.25	.02	.28	No. 1 Gray,	Hartman, *Jour. Frank. Inst.*, Vol. CXXXIV, p. 122.
2	92.81	2.99	0.37	2.52	1.08	.02	.72	No. 2 Gray,	
3	94.68	2.50	1.52	.72	.26	tr.	.34	No. 3 Gray,	
4	94.48	2.02	1.98	.56	.19	.08	.67	Mottled,	
5	94.68	. . . .	3.88	.41	.04	.02	.98	White,	
6	. . .	. . . .	4.27	1.10	. . .	. .	8.11	Spiegel,	
7	. . .	. . . .	4.78	.52	. . .	. .	19.74	"	
8	. . .	. . . .	5.63	.42	. . .	. .	41.52	Ferro-manganese,	
9	. . .	. . . .	6.53	.97	. . .	. .	80.04	"	
10	. . .	. . . .	7.20	.14	. . .	. .	80.04	"	
11	. . .	. . . .	3.56	4.90	. . .	. .	28.90	Silico-spiegel,	Hadfield, *Journal I. and S. I.*, Vol. II, 1889, p. 226.
12	. . .	. . . .	2.16	4.20	. . .	. .	50.00	"	
13	. . .	.33	1.85	10.74	. . .	. .	19.64	"	
14	. . .	.67	.98	12.60	. . .	. .	19.74	"	
15	. . .	.90	.20	15.94	. . .	. .	24.86	"	
16	. . .	2.35	.05	8.77	. . .	. .	2.42	Ferro-silicon,	
17	. . .	1.85	.06	11.20	. . .	. .	2.78	"	
18	. . .	1.20	.23	14.00	. . .	. .	1.95	"	
19	. . .	.55	.11	17.80	. . .	. .	1.07	"	

some irons contain one per cent. or more, but this element is undesirable to the steel maker. Vanadium, arsenic and many other elements are often present in iron where their presence is not suspected, but in quantities so minute as to be harmless. The composition of various pig-irons and spiegels is shown in Table II-I.

SEC. IIx.—*The structure of cast-iron.*—The structure of cast-iron has been thoroughly investigated by Prof. Howe. He argues that pig-iron and steel form a continuous series; that steel is a grade of cast-iron, and cast-iron a grade of steel. It is well known that steel is a mixture or alloy of two components, ferrite and cementite; but these two substances combine together in one definite proportion, and in one proportion only, to form pearlite. The proportion is seven parts of ferrite to one of cementite, so that pearlite contains about 0.80 per cent. of carbon. Steel or iron containing more than 0.80 per cent. of carbon cannot all be pearlite, but the pearlite which is present will contain, if the metal is cooled slowly, the full quantity of carbon represented by 0.80 per cent. of the mass, and the rest of the carbon will exist in some other form;

part may exist in combination as cementite, and part as graphite. Steel containing 0.90 per cent. of carbon, if cooled slowly, will be mostly pearlite, but will usually contain a trace of graphite and some cementite. Pig-iron with 4 per cent. of carbon cannot contain more pearlite than the steel just mentioned, but there will be just so much more carbon to form either graphite or cementite. The amount of graphite will depend upon several conditions. A hot blast furnace will give a higher percentage than a cold furnace, and high silicon will also cause the separation of free carbon, while manganese and sulphur will cause the carbon to remain combined.

Cast-iron with 1.25 per cent. combined carbon is really steel, but weakened and embrittled by graphite. In the same way cast-iron with 3 per cent. of combined carbon plus 1 per cent. of graphite is a mechanical mixture of two substances: (1) 99 parts white cast-iron containing 3 per cent. of combined carbon, and (2) 1 part of graphite. The contention that graphite "weakens and embrittles" cast-iron is founded on the fact that pig-irons containing the same proportion of silicon, manganese and sulphur carry the same proportion of total carbon, no matter whether they are gray or white. An increase in graphite means a decrease in combined carbon, and since one-quarter of the carbon is in the form of pearlite, and since cementite must contain 6.57 per cent. of carbon, it follows that if much carbon exists as graphite, the proportion of cementite decreases and the proportion of soft ferrite increases, with a toughening of the mass. This toughening is usually ascribed to graphite, when in reality the graphite weakens the iron by destroying its continuity. Thus silicon will toughen iron because it drives the carbon into the condition of graphite, while manganese will make it brittle because it causes it to combine.

CHAPTER III.

WROUGHT-IRON.

SECTION IIIa.—*The puddling process.*—When pig-iron is melted on a hearth of iron ore and is exposed to the action of the flame, there is a rapid oxidation of the metalloids. The silicon, manganese, sulphur and phosphorus unite with oxygen to form a slag, while the carbon escapes as carbonic oxide and carbonic acid. The iron then becomes less fusible, and in an ordinary reverberatory furnace the heat is not sufficient to keep the mass liquid. It becomes viscous, then pasty, and finally is worked into balls, taken from the furnace, and squeezed or hammered into a bloom.

The crude puddle-ball is made up of an innumerable number of globules of nearly pure iron, while the interstices between the particles are filled with slag. The squeezer expels much of this slag and each subsequent rolling removes a further quantity, but it is impossible to get rid of all the cinder, and it forms a skeleton which permeates the finished bar, forming planes of separation between the particles of metallic iron. These films weaken the material by destroying the cohesion of the particles, but in other ways they are of benefit, for the sulphur and phosphorus are never entirely removed in puddling, and there is usually a sufficient percentage of them left to give bad results if they were able to exert their full effect in producing crystallization, but the network of slag prevents the tendency to crystallize. If bar-iron be melted in a crucible, the slag separates and the impurities have a chance to exert their full force. Some pure irons will successfully undergo this test, but most brands give a worthless metal after fusion. The first rolling of the puddle-ball gives a crude product known as muck-bar. For the making of merchant iron, this intermediate product, together with miscellaneous wrought-iron scrap, is bundled into "piles" and rolled into the desired shape.

SEC. IIIb.—*Effect of silicon, manganese and carbon.*—The char-

acter of the product will depend upon its chemical composition, and this in turn upon the composition of the pig-iron from which it is made and upon the care and skill with which the operation has been conducted. There are five elements commonly found in pig-iron which have an important bearing on the finished material.

Silicon.—This element may be regarded as an almost unmitigated evil, since it produces silica which is not wanted in a basic slag. Moreover, its union with oxygen does not form a gas, and during its elimination the bath lies dead and sluggish. Metallic iron is set free by the absorption of oxygen from the ore, but this is more than offset by the iron oxide which is held by the silica. Some silicon is oxidized during the melting, so that the boil begins very soon after fusion. With workmen accustomed to high silicon iron, there is considerable waste in using a lower grade, because the latter melts at a higher temperature, and, since there is not enough silica produced from the portions first melted to give a proper quantity of slag, the bare metal is exposed after melting to a hot flame and fumes of iron oxide escape to the stack. The same trouble is experienced in changing from a pig-iron cast in sand to one cast in chills, but this loss in both cases can be avoided by regulating the operation so that all the iron is melted at one time, and by keeping the metal covered with a fluid cinder, better results being obtained, both in time and waste, than with an iron containing a higher percentage of silicon, or one which carries adhering sand.

Manganese.—Although acting in the same way as silicon in giving a dead bath, manganese is not as objectionable, for its oxide is a base which replaces an equal quantity of iron oxide, and aids in the elimination of sulphur.

Carbon.—Speaking only of ordinary forge-irons, it may be said that the carbon runs from 3.0 to 4.0 per cent. It is often supposed that a mottled or white iron will necessarily be low in this element, but such is by no means a certainty, for the close grain may arise from low silicon, which is an advantage, from high manganese, which is a disadvantage, or from sulphur, which is a decided injury. Low carbon, moreover, is not a vital matter, for although this element lengthens the boil, it facilitates fusion, and its union with the oxygen of the ore reduces metallic iron without forming any objectionable component of the slag.

SEC. IIIc.—*Sulphur and phosphorus in the puddling furnace:*

Sulphur.—The content of sulphur in pig-iron is determined more by the working of the blast furnace than by the nature of the ore; but the demand for a low-silicon, low-carbon, close-grained iron for the puddler sometimes results in a pig containing from .10 to .50 per cent. of sulphur. This is reduced in the process of puddling by passing away as sulphurous acid and by being carried off in the cinder.

Phosphorus.—This element is under more or less control, and it may be roughly stated that three-quarters of the total content may

TABLE III-A.

Elimination of the Metalloids in Puddling.

Nature of Sample.	Composition, per cent.											
	Metal.						Slag.					
	Si	Carbon		Mn	P	S	SiO_2	SiO_2	Fe_2O_3	FeO	MnO	P_2O_5
Pig Iron No. 1,	2.80	3.12		. .	1.47	.11	. . .	. . .	. . .	. . .	. . .	. . .
Refined,	.12	2.50		. .	.54	tr.	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.19	tr.		. .	.27	tr.	. . .	. . .	. . .	. . .	. . .	. . .
Pig Iron No. 2,	1.236	3.180		. .	1.494	.111	. . .	. . .	. . .	. . .	. . .	. . .
After melting,	.821	2.880		. .	.918	.096	. . .	. . .	. . .	. . .	. . .	. . .
During the boil	.300	2.800		. .	.582	. . .	. . .	. . .	. . .	. . .	. . .	. . .
" " "	.051	1.170		. .	.519	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.098	.150		. .	.452	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Pig Iron No. 3,	1.36	3.20		. .	1.39	.17	. . .	. . .	. . .	. . .	. . .	. . .
Refined,	.07	2.00		. .	.32	.06	. . .	. . .	. . .	. . .	. . .	. . .
Forming into grain,	.04	1.90		. .	.20	.02	. . .	. . .	. . .	. . .	. . .	. . .
Dropping on grain,	.04	1.15		. .	.30	tr.	. . .	. . .	. . .	. . .	. . .	. . .
Finished bar,	.07	.05		. .	.33	.04	. . .	. . .	. . .	. . .	. . .	. . .
		Comb.	Graph.									
Pig Iron No. 4,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
After melting,	1.11	0.61	1.75	.78	.86	. . .	. . .	24.04	18.74	51.22	4.42	1.30
Bath growing thicker,	.14	1.89	tr.	tr.	.25	. . .	. . .	27.17	5.28	59.56	5.17	2.12
Coming up on boil,	. . .	1.75		. .	.09	.26	. . .	.74	27.77	4.81	59.95	5.29	2.19
Beginning to drop,	. . .	1.57		. .	tr.	.23	. . .	1.01	27.46	4.19	58.41	55.45	2.22
Dropped; infusible,	. . .	1.10		. .	tr.	.23	. . .	1.37	25.72	4.20	60.61	4.65	2.07
Balling,	. . .	.25		. .	tr.	.25	. . .	.91	15.79	9.21	69.52	2.81	1.66
Finished bar,	. . .	.16		. .	.07	.09	. . .	.28	. . .	. . .	. . .	. . .	. . .

NOTE.—The data on pig-irons Nos. 1, 2 and 3 are taken from investigations by Bell; see *Journal I. and S. I.*, Vol. I, 1877, pages 120 and 122.

Those on No. 4 are from a paper by Louis, *Journal I. and S. I.*, Vol. I, 1879, p. 222, it being stated that after the fourth test it was impossible to get a fair average owing to the viscosity of the mass.

be eliminated, this broad formula being profoundly influenced by the skill of the puddler and the purity of the reagents. The chemical history of the puddling process is shown by Table III-A.

SEC. IIId.—*Effect of the temperature upon puddling.*—The temperature of the furnace has an important bearing on the character of the product, particularly when much carbon is present. Experiments by Stead* show that in the refining process, which corresponds to the first part of the puddling process, the elimination of phosphorus was inversely as the temperature, ranging from 46 per cent. in hot charges to 91 per cent. with cold working, in each case about 96 per cent. of the silicon and 30 to 40 per cent. of the carbon being oxidized. For many years the phenomenon was explained by supposing that phosphorus would not unite with oxygen at high temperatures, and this was deemed to be proven by the fact that phosphorus was not burned in the acid Bessemer converter. It is now known that the reduction of phosphorus by high heat in the puddling furnace is due to the simple fact that carbon has a greater affinity for oxygen as the temperature rises, so that it reduces the phosphate of iron and returns the phosphorus to the metal.

It is the practice at most works to remove part of the slag while the metal is high in carbon, the product being called "boilings," while the slag which is left in the furnace at the end of the operation and which is sometimes tapped from the bottom is called "tappings." This last cinder is often allowed to remain, or, if tapped, is charged with the next heat to furnish a rich slag in the early part of the process, since the fettling of iron ore is so infusible that it cannot furnish a cinder until a high temperature is attained. The removal of the "boilings" during the operation hastens the work, gives less cutting of the bottom, and renders the "balling" easier. It also aids dephosphorization, for during the first part of the operation the charge is at a low temperature, and the slag carries a higher percentage of phosphorus than it would retain if it were kept in the furnace and exposed to a high temperature and the reducing action of carbon. By tapping during the first part of the boil, the greater part of the silica and phosphorus is removed and there is an opportunity to make a new slag richer in iron and of

* *Journal I. and S. I.*, Vol. II, 1877, p. 372.

greater dephosphorizing power. The first slag is known as puddle or mill cinder and is often used in the blast furnace. It is variable in composition, as shown in Table III-B.

TABLE III-B.

Composition of Puddle or Mill Cinder.

Where Made.	Authority.	Composition, per cent.				
		SiO_2	Fe	P	Mn	S
Harrisburg, Pa.,	Author.	19.91	49.07	1.10	1.27	....
"	"	11.64	60.86	1.07	....	....
"	"	19.58	55.06	1.81	....	0.24
"	"	21.88	56.04	1.41	3.62	...
Troy, N. Y.,	*Trans. A. I. M. E.*, Vol. IX, p. 14,	13.81	58.44	1.91	....	....
Ironton, Ohio,	*Trans. A. I. M. E.*, Vol. IX, p. 14,	30.00	50.59	0.54	....	....
Marietta, Ohio,	*Trans. A. I. M. E.*, Vol. IX, p. 14,	21.58	51.42	1.40	....	....
Three English Works, "Boilings,"	*I. and S. I.*, Journal, Vol. I, 1891, p. 119,	19.45	58.55	2.76	....	....
Three English Works, "Tappings,"	*I. and S. I.*, Journal, Vol. I, 1891, p. 119,	15.47	59.29	1.71	....	....

SEC. IIIe.—*Effect of work upon wrought-iron.*—The influence of different elements upon wrought-iron has never been fully discovered, owing to many disturbing conditions, foremost among which is the effect of varying amounts of work upon the finished material. This question arises in the case of steel, but is more important in wrought-iron, since the strength of the bar will depend upon the thoroughness with which the pieces forming the mass have been welded together. In Table III-C are given results obtained at the Central Iron and Steel Works at Harrisburg, Pa., from plates rolled on their three-high train, and on a 25-inch universal mill. The better figures for the latter mill are due to the more complete development of fiber by the continuous rolling in one direction. The width was alike for similar thicknesses, and no difference was found in the universal plates whether they were 9 or 42 inches in width.

Usually there is a retrogression in quality as the size of the finished piece increases, and this is recognized in specifications.

SEC. IIIf.—*Heterogeneity of wrought-iron.*—The most complete investigation on the subject of wrought-iron is a report by

Holley* on the work of a Board appointed by the United States Government to test material for chain cables. It was found that the tenacity of 2-inch bars for chain cables should be from 48,000 to

TABLE III-C.

Wrought-Iron Plates from Shear and Universal Mills.

Sheared Plates.						Universal Mill Plates.				
Thickness in inches.	Number of tests averaged.	Elastic limit, lbs. per square inch.	Ultimate strength, lbs. per square inch.	Elongation in 8 in., per cent.	Reduction of area, per cent.	Number of tests averaged.	Elastic limit, lbs. per square inch.	Ultimate strength, lbs. per square inch.	Elongation in 8 in., per cent.	Reduction of area, per cent.
[illegible]	1	32400	51800	11.2	18.9	1	32100	51000	13.0	19.9
[illegible]	. .	. . . .	. . . .	. . .	. . .	2	31050	50650	14.6	21.6
[illegible]	5	31180	49760	14.2	22.0	3	31100	50580	17.3	26.2
[illegible]	4	30775	50200	15.5	22.5	3	30500	50330	17.2	24.6
[illegible]	2	30400	49050	16.0	22.4	3	31470	52570	19.0	26.2

52,000 pounds per square inch, while 1-inch bars should show 53,000 to 57,000 pounds. This conclusion illustrates the profound influence of reduction in rolling. The slag varied from 0.192 per cent. to 2.262 per cent. of the total weight of the iron. Some makers may have supposed that slag would facilitate welding, but the investigation did not bear this out, for it is distinctly stated that, while "slag should theoretically improve welding, like any flux, its effect in these experiments could not be definitely traced." On the contrary, the iron highest in slag (2.26 per cent.) "welded less soundly than any other bar of the same iron, and below average as compared with the other irons." The percentage of slag not only varied in different brands of iron, but in pieces of the same make. This was true also of all the factors investigated. Table III-D shows the variations in the same make of iron, two extreme cases being given under each head. It also gives the maximum and minimum individual records.

SEC. IIIg.—*Conditions affecting the welding properties.*—Conditions of varying work, percentages of slag, and irregularity of the same irons, not to mention the possible overheating of piles, com-

* *The Strength of Wrought-Iron as Affected by its Composition and by its Reduction in Rolling. Trans. A. I. M. E.*, Vol. VI, p. 101.

plicate the relation between the chemical composition and the physical properties, and it need not be wondered that the committee could not find the exact influence of each chemical component.

TABLE III-D.

Variations in Specimens Submitted to the United States Board for Testing Chain Cables.

Subject.	Same Iron		All Irons.	
	Min.	Max.	Min.	Max.
Carbon, per cent.,	.026 .042	.064 .512	.015	.512
Phosphorus, per cent.,	.066 .096	.232 .250	.005	.317
Silicon, per cent.,	.028 .182	.182 .321	.028	.321
Manganese, per cent.,	tr. .021	.059 .097	tr.	.097
Slag, per cent.,	0.674 1.248	1.738 2.262	0.192	2.262
Ultimate strength, pounds per square inch,	56201 47478	69779 57867	47478	69779
Elongation in 8 inches, per cent.,	11.7 14.1	20.6 32.5	6.5	32.7
Reduction of area, per cent.,	27.7 16.0	59.8 31.5	7.7	59.8

There was formulated, however, the following valuable conclusion: "Although most of the irons under consideration are much alike in composition, the hardening effects of phosphorus and silicon can be traced, and that of carbon is obvious. Phosphorus up to .20 per cent. does not harm and probably improves irons containing silicon not above .15 per cent. and carbon not above .03 per cent. None of the ingredients, except carbon in the proportions present, seem to very notably affect the welding by ordinary methods." Regarding this last clause it should be said that the highest sulphur in any sample was .015 per cent., which is low; but copper was present up to .43 per cent.; nickel up to .34 per cent., and cobalt up to .11 per cent. Moreover, the high percentages of these three elements were coincident in one bar, yet welding gave fair results, notwithstanding that phosphorus was higher than was advisable. The experiments were far from conclusive as to these elements.

CHAPTER IV.

STEEL.

A true definition of steel must apply not only to the metals commonly designated by the term, but to all compounds which ever have been, or ever will be, worthy of the name, including the special alloys made by the use of chromium, tungsten, nickel and other elements. Prior to the development of the Bessemer and open-hearth processes there was little room for disagreement as to the dividing line between steel and iron. If it would harden in water, it was steel; if not, it was wrought-iron. By degrees these processes widened their field, and finally began to make a soft metal which possessed many of the characteristics of ordinary wrought-iron. It then became a matter of great importance to have a proper system of nomenclature, since the filling of engineering contracts and the interpretation of tariff schedules depended upon the application of the one term or the other to the soft product of the converter and the melting-furnace.

At this juncture an international committee was appointed with a formidable array of well-known names: Holley, Bell, Wedding, Tunner, Akerman, Egleston and Gruner. This committee reported in October, 1876, to the American Institute of Mining Engineers, the following resolution:

(1) That all malleable compounds of iron with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any forms of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called "wrought-iron," shall be called *weld iron.*

(2) That such compounds, when they will from any cause harden and temper, and which resemble what is now called "puddled steel," shall be called *weld steel.*

(3) That all compounds of iron with its ordinary ingredients which have been cast from a fluid state into malleable masses, and

which will not sensibly harden by being quenched in water while at a red heat, shall be called *ingot iron.*

(4) That all such compounds, when they will from any cause so harden, shall be called *ingot steel.*

Needless to say, these definitions have long since been forgotten, for they ignored current usage. They are given here because the terms are encountered occasionally in books, and are used to some extent abroad. Strictly speaking, some mention must be made of hardening in a complete definition, for it is possible to make steel in a puddling furnace by taking out the viscous mass before it has been completely decarburized; but this crude method is a relic of the past, and may be neglected in practical discussion. No attempt will be made to give an ironclad formula, but the following statements portray the current usage in our country:

(1) By the term wrought-iron is meant the product of the puddle furnace or the sinking fire.

(2) By the term steel is meant the product of the cementation process, or the malleable compounds of iron made in the crucible, the converter, or the open-hearth furnace.

This nomenclature is not founded on the resolutions of committees. It is the natural outgrowth of business, and has been made mandatory by the highest of all statutes—the law of common sense. It is the universal system among engineers, not only in America, but in England and in France. In other lands the authority of famous names, backed by conservatism and governmental prerogative, has fixed for the present, in metallurgical literature, a list of terms which is not only deficient, but fundamentally false.

CHAPTER V.

HIGH-CARBON STEEL.

SECTION Va.—*Manufacture of cement and crucible steel.*—With pure ores and skillful puddling, it is possible to produce wrought-iron in which the phosphorus does not exceed .02 per cent. This pure iron may be converted into steel by placing it in fine charcoal and exposing it to a yellow heat. By a slow process, called cementation, the carbon penetrates the metal at the rate of about one-eighth inch every 24 hours, so that a bar five-eighths of an inch thick is saturated about 48 hours after it arrives at a proper temperature. Many tons of bars are treated at one time, and some arrive at a full heat much sooner than others, and remain longer at that temperature, so that it is necessary to break the bars after treatment and grade them by fracture. The point of saturation is about 1.50 per cent. of carbon, but the average will be about one per cent.

The steel thus produced is known as blister or cement steel. It contains seams and pits of slag which were in the wrought-iron, and these defects are of fatal moment in the manufacture of edged tools. To avoid this trouble, cement steel may be melted in crucibles, out of contact with the air, and, being thus freed from the intermingled slag, can be cast into ingots. This double process is expensive, and a more common method is to put charcoal into the crucible with bar-iron, the absorption of carbon progressing with rapidity when the metal is fluid. This practice is almost universal in America, and it is claimed that it gives a steel equal in every respect to the older method, but against this it may be well to quote the following dictum of Seebohm,* which expresses the ancient doctrines: "The best razor steel must be melted from evenly converted steel. It will not do to mix hard and soft steel together, or to melt it from pig 'let down' with iron, for it will not then possess the requisite amount of body, and the edge of the razor will not stand."

* *On the Manufacture of Crucible Cast-Steel. Journal I. and S. I.*, Vol. II. 1884, p. 372.

A third variation is the melting of wrought-iron with a proper proportion of pig to raise the carbon to the desired point, while in still another, used in Sweden, the charge of the crucible consists of pig and iron ore. The aim of all methods is to obtain a malleable metal containing from .60 to 1.40 per cent. carbon, and free from blowholes. For certain purposes some special element like chromium, or tungsten, may be used as an alloy, but with this exception every other ingredient may be regarded as an impurity.

SEC. Vb.—*Chemical reactions in the crucible.*—The best tool steel must be as tough as possible, and, therefore, the phosphorus should not be over .02 per cent. Sulphur, which does not appreciably affect brittleness, but does decrease forgeability, is not so important, but should not exceed .04 per cent. Manganese may be in larger quantity, and it is not uncommon to put into the pot a mixture of manganese ore and carbon so that metallic manganese may be reduced. If the percentage does not exceed .20 it has little bad effect; if much above this, it will cause brittleness and liability to crack in quenching.

Just after the steel is melted there is more or less action in the crucible. In addition to the iron and charcoal in the pot, there is a small amount of glass or similar material to give a passive slag; also a little air, some slag and oxide of iron, the scale and rust on the surface of each piece of metal, and silica, alumina and carbon from the scorification of the walls. A little time is necessary for the various reactions to occur and for the reduction of silicon from the slag and lining in accordance with the following equation:

$$SiO_2+2C=Si+2CO.$$

The carbon is drawn either from the charcoal, from the metal, or from the crucible. In the case of graphite pots the supply from the latter source will be ample, while even clay pots furnish quite an amount from the coke which is mixed with the clay. This reduction goes on until the steel contains from .20 to .40 per cent. of silicon and the metal lies quiet and "dead," when the pot is taken from the furnace and the contents cast into ingot form. The crucible lasts from four to six heats, and the weight of a melt is about 80 pounds when the crucible is new.

SEC. Vc.—*Chemical specifications on high steel.*—In olden

times all springs, tools, dies, and the like were made from either cement or crucible steel, but in late years large quantities of high-carbon metal have been produced in the Bessemer converter. The manganese in Bessemer steel is much higher than in crucible metal, and this has a tendency to cause cracks in quenching. Formerly a content of .75 to 1.10 per cent. was not uncommon, but the demands of the trade have forced an improvement in this respect. It is possible to make a better selection of the stock for an open-hearth furnace and produce a steel low in manganese, phosphorus, and sulphur. The relative merits of open-hearth and crucible steel have been vigorously discussed, but oftentimes a comparison is made between a pure crucible steel and an impure open-hearth metal, and the conclusion formulated that crucible steel is much superior. No comparison is valid unless the steels are of the same composition, and in this latter respect it will not do to accept the unproven statements of makers. Table V-A gives analyses of three grades of steel, furnished by one of the well-known steel manufacturers of the country.

TABLE V-A.

Commercial High Steels Not According to Specifications.

Nature of sample as marked by maker.	Composition; per cent.				
	C	P	Mn	Si	S
"Crucible"	1.00	.04	.88	.02	.026
"Pennsylvania Railroad spring"	.94	.065	.56	.28	.125
"Low phosphorus spring"	.80	.072	.64	.19	.155

The carbon content is right, but each sample shows discrepancies between actual composition and name. Crucible steel may contain as much as .04 per cent. of phosphorus, but no purchaser expects that amount, and when this is considered in connection with the high manganese, and the absence of silicon, the natural conclusion is that the metal ran from an open-hearth furnace. The second sample was supposed to fill the Pennsylvania Railroad specifications for springs which at that time called for phosphorus below .05 per cent., manganese below .50 per cent., and sulphur below .05 per cent., but a glance will show the liberties that were taken. The "phosphorus" spring steel contains .072 per cent. of that element, an amount slightly under the average of common rails.

SEC. Vd.—*Manufacture of high steel in an open-hearth furnace.*—It is possible to make open-hearth steel of any carbon from .05 to 1.50 per cent., with phosphorus below .04 per cent., manganese below .50 per cent., and sulphur below .04 per cent. During the last few years this steel has come into general use and all car springs and similar articles are of open-hearth steel. It is used extensively under the name "cast steel," a term which is both a truth and a lie: the truth because the steel is cast; a lie because "cast steel" is a trade name dating back a century, and meaning the product of the crucible.

There are one or two points about this material which should be recognized by maker and user. First, there is less opportunity to get a "dead melt" in the furnace, and hence there is more liability of blowholes in the ingots and seams in the bar. For making

TABLE V-B.

Clippings from the Top* and Bottom of Each Ingot of a High-Carbon Heat.

Number of Ingot.	Part of Ingot.	Composition; per cent.					
		Carbon by Combustion.	P	Mn	S	Si	Cu
1	Top	1.009	.030	.30	.027	.14	.10
	Bottom	1.060	.031	.29	.026	.18	.10
2	Top	1.046	.029	.29	.027	.15	.10
	Bottom	1.006	.026	.29	.027	.13	.10
3	Top	1.042	.031	.29	.028	.11	.10
	Bottom	0.988	.030	.30	.029	.14	.10
4	Top	1.000	.032	.28	.028	.09	.10
	Bottom	1.027	.034	.29	.025	.12	.10
5	Top	0.948	.035	.32	.026	.17	.10
	Bottom	1.089	.036	.29	.027	.10	.10
6	Top	1.065	.030	.28	.026	.11	.10
	Bottom	1.086	.033	.29	.026	.11	.10
7	Top	1.073	.030	.29	.025	.11	.09
	Bottom	1.042	.028	.30	.028	.15	.10
8	Top	0.962	.029	.30	.025	.12	.10
	Bottom	0.953	.032	.29	.026	.13	.08
9	Top	1.044	.031	.29	.026	.11	.09
	Bottom	0.915	.032	.28	.027	.13	.10
Test.		1.073	.030	.28	.033	.12	.07

*The piece from the upper bloom was from a point one-quarter way from the top of the ingot, and near the point of maximum segregation. The sample was the clipping produced in cutting a billet under the hammer.

razors, watch-springs and other delicate instruments, no expense is too great in avoiding minute defects, but when these imperfections are few and not of vital importance, there must be a tendency to economize in the cost of the raw material. Second, a heavy heat of open-hearth steel must be cast in masses which are large in comparison with the 4-inch ingot of the crucible works, and the chances for segregation are correspondingly increased, although Table V-B will indicate that with proper precautions there is little danger of trouble.

Some interesting experiments were made by Wahlberg, who took tests from the top and bottom of high-carbon ingots made at four well-known works in Sweden. He found a difference in the carbon content of the outer skin of the ingot at the top and at the bottom amounting, in the four different ingots, to the following in per cent.:

.13 .06 .09 .09

The differences at the center of the ingot between top and bottom were, respectively, .19, .05, .13 and .09 per cent. Wahlberg gives the carbon as "branded" on the bar. It may be well to compare this with the results obtained by the chemists, and Table V-C gives this information, the maximum and minimum in each case being obtained from the top and bottom of the same ingot.

TABLE V-C.

Variations in Swedish Steel.

Brand.	Carbon per cent.	
	Maximum.	Minimum.
50	46	49
50	58	61
50	49	55
62	59	69
90	88	106
100	88	105
110	107	119
124	114	131

In the Steelton steels, the variations in phosphorus, sulphur, manganese and copper are trifling, while those of silicon are unimportant. In carbon the difference between extremes is 16 points,

and while this may seem to be a great variation in one charge, the variations in each separate ingot were less than in the Swedish steel. The average variation between the top and bottom of a Steelton ingot was .07 per cent. A true comparison is not between one ingot of crucible steel and a heat of open-hearth metal. The question is whether the irregularities are greater in ten tons of crucible steel than in ten tons of open-hearth. Much depends upon the care with which the stock is selected, but Table V-D gives analyses of different bars of one lot of crucible steel, sold under one mark and of uniform size by one of the leading firms in the United States; it will be evident that uniformity can, by no means, be assumed.

TABLE V-D.

Variations in One Lot of Crucible Steel.

No. of Bar	Composition, per cent.			
	Carbon by color.	P	Mn	S
1	.85	.013	.20	018
2	.85	.011	.20	014
3	1.05	.010	.17	010
4	.98	.013	.21	.012
5	.90	und.	.28	.010

CHAPTER VI.

THE ACID BESSEMER PROCESS.

SECTION VIa.—*Construction of a converter.*—The acid Bessemer process consists in blowing air into liquid pig-iron for the purpose of burning most of the silicon, manganese and carbon of the metal, the operation being conducted in an acid-lined vessel, and in such a manner that the product is entirely fluid.

The way the air is introduced is of little importance. In the earlier days there were many forms of apparatus, the air being blown sometimes from the side and sometimes from the top, while the tuyeres were plunged beneath the surface or raised above it. These forms have given way in large plants to the method of blowing the air upward through the metal, trusting to the pressure of the blast to keep the liquid from running into the holes in the bottom, but where converters are used for making steel castings the method of side blowing is employed, for with intermittent work and where there is difficulty in getting the metal hot, the blast over the surface is an advantage. The converters vary in size, in exceptional cases holding less than one thousand pounds, but the common size for what are known as "small" plants treats five tons at a time, while in the "large" plants the capacity is from ten to twenty tons.

In Fig. VI-A are given drawings of the 18-ton vessels in use at the works of the Maryland Steel Company, at Sparrow's Point, Md. The converters are rotated on a central axis by means of a rack and pinion, to allow the turning down of the vessel as soon as the charge is decarburized, so that the metal may lie quietly in the belly, the tuyeres being above the metal. In this way the blast can be stopped without filling the tuyeres with molten metal. If bottom blast be used with a stationary vessel, the blast must be continued during the time required to open the tap-hole and drain out the metal, so that the results will be more irregular than with a

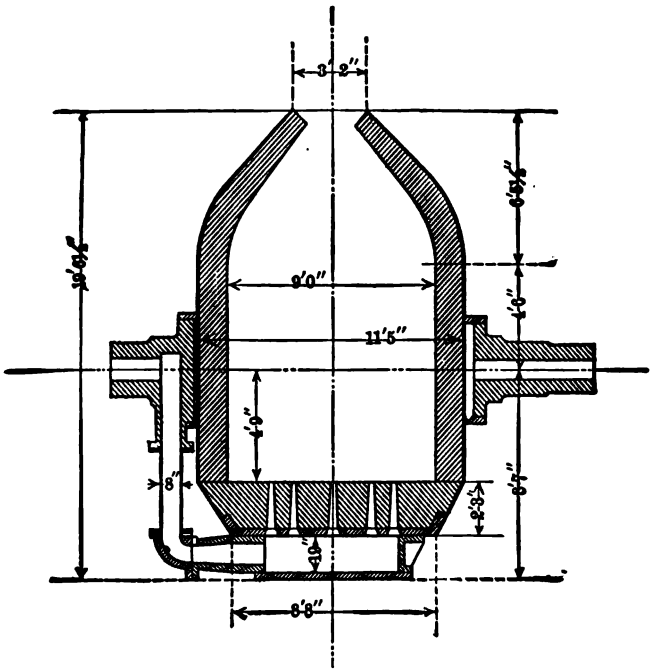


FIG. VI-A.—BESSEMER CONVERTER IN UPRIGHT POSITION

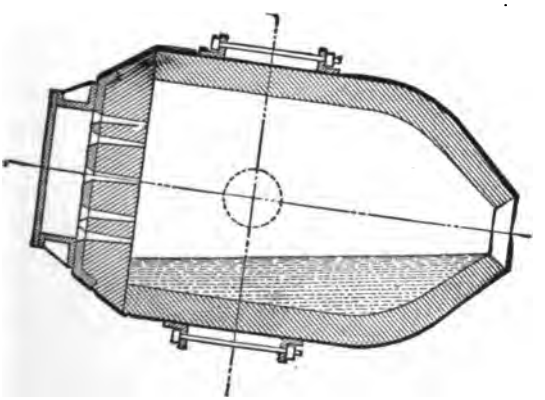


FIG. VI-A.—BESSEMER CONVERTER WHEN TURNED DOWN, SHOWING BATH OF METAL.

rotary form. This fault may be partly overcome by having the blast introduced from the upper surface, but the waste of iron is greater, and the extra expense wipes away all advantages of a reduced cost of installation.

TABLE VI-A.

Chemical History of an Acid Bessemer Charge.

Illinois Steel Company, South Chicago, Ill., August 13, 1890, F. Julian.
Barometer, 29.79 inches; temperature, 36° C. (96.8° F.); blast pressure, 27 pounds. No allowance for leakage and clearance. Weight of pig, 22,500 pounds.

Subject.	Initial Charge.	Time of Blowing.					
		2m. 0s.	3m. 20s.	6m. 3s.	8m. 8s.	9m. 10s.	After Spiegel.
Carbon	2.98	2.94	2.71	1.72	0.53	0.04	0.45
Silicon	0.94	0.63	0.33	0.03	0.03	0.02	0.038
Manganese	0.43	0.09	0.04	0.03	0.01	0.01	1.15
Phosphorus	.10	0.104	0.106	0.106	0.107	0.108	0.109
Sulphur	.06	0.06	0.06	0.06	0.06	0.06	0.059
Silica	.....	42.40	50.26	62.54	63.56	.....	62.20
Alumina	.....	5.63	5.13	4.06	3.01	.....	2.76
Ferrous oxide	.....	40.29	34.24	21.26	21.39	.....	17.44
Ferric oxide	.....	4.31	0.96	1.93	2.63	.....	2.90
Manganese oxide	.....	6.54	7.90	8.79	8.88	.....	13.72
Lime	.....	1.22	0.91	0.88	0.90	.....	0.87
Magnesia	.....	0.36	0.34	0.34	0.36	.....	0.29
Phosphorus	.....	0.008	0.008	0.010	0.014	.....	0.010
Sulphur	.....	0.009	0.009	0.014	0.008	.....	0.011
Flame	.....	Silicon flame.	bright-ening.	m'der'te carbon flame.	full carbon flame.	flame drops.	.....
Cubic feet of air	.....	34502	38028	53481	45365	26430	.....

The lining is of stone, brick, or other refractory material and is about one foot thick. The bottom is either of brick or rammed plastic material, the tuyeres being of brick, from 20 to 26 inches in length, with holes from three-eighths to one-half inch in diameter. The total tuyere area varies at different works from 2.0 to 2.5 square inches per ton of charge. The blast pressure may be 30 pounds per square inch during the first period of the blow, but there has been a tendency toward greater tuyere area and a reduction in the pressure to about 20 pounds or less. In a very hot charge, or if the slag is sloppy, the pressure must sometimes be reduced to 10 pounds after the flame "breaks through" (i.e., after the carbon begins to burn), to prevent the expulsion of metal from the nose. The blowing engine and the tuyere openings being proportionate to the work in hand, the heats, whether heavy or light, are usually blown in from 7 to 12 minutes.

SEC. VIb.—*Chemical history of a charge.*—The chemical history of a charge was investigated by F. Julian, of the Illinois Steel Company, and his results are given in Table VI-A, which is copied

from a paper by Prof. Howe.* The results on the slags are not accurate, for it is impossible to take a true sample of converter slag, on account of its viscosity. An attempt to work out the weight of the cinder at different periods of the blow showed that there were considerable discrepancies; the combustion of the metalloids is not in proportion to the amount of air given as entering the vessel, while the total oxygen in the recorded volume of air is twice the amount needed for the silicon, manganese and carbon. Notwithstanding these errors, the table represents the chemical operations in the vessel. The presence of phosphorus in the slag is attributed by Prof. Howe to shot mechanically held. This is hardly the whole story, for I have found that acid open-hearth slag with 50 per cent. SiO_2 may carry 0.04 per cent. of phosphorus, and this must arise, in part at least, from an absorption of phosphorus by oxide of iron. The failure of the silica to break up the phosphate of iron may be explained by the persistence with which traces of elements refuse to be eliminated under conditions which suffice for the removal of all but an inconsiderable proportion. I have elsewhere† dwelt upon this fact.

SEC. VIc.—*Variations due to different contents of silicon.*—With a low initial heat, the elimination of silicon is almost complete before the carbon is seriously affected, but there is a critical temperature where the relative affinities of silicon and carbon for oxygen are reversed, and, when this is attained, no matter at what stage of the operation, the silicon immediately ceases to have preference, and the carbon seizes the entire supply of oxygen. This continues until the carbon is reduced to about .03 per cent. If the metal has contained silicon during the burning of carbon, owing to an excessively high temperature, the blowing may be kept up after the drop of the carbon flame and the silicon will be oxidized in preference to iron, but in ordinary practice silicon is eliminated early in the operation, for scrap is added to the charge in sufficient quantity to utilize the excess of heat. The same cooling effect may be attained by the injection of steam into the air supply.

It has been the practice at many foreign works to have the pig-iron at a high temperature in the manufacture of rail steel, and blow "hot" to produce a decarburized metal containing silicon. The

* *Notes on the Bessemer Process. Journal I. and S. I.*, Vol. II, 1890, p. 102.
† *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 462.

steel is cooled to a proper casting temperature by the addition of scrap in the ladle, and large quantities of rails and other products have been thus made with from 0.3 to 0.6 per cent. of silicon. Some pig-iron, notably in Germany and Sweden, contains a considerable proportion of manganese; this burns, in some measure, at the same time as the silicon; but when the manganese is present in large quantity, the carbon has preference. In Sweden this fact is made use of in the manufacture of tool steels, the operation being stopped when the bath is high in carbon, the metal still containing a sufficient proportion of manganese to insure good working.

SEC. VId.—*Swedish practice.*—The Swedish practice has been discussed by Akerman,* and many of the following statements are founded on his authority. The pig-iron contains not much over 1.0 per cent. of silicon to insure that the product shall be free from this metalloid, even if the blow be interrupted when high in carbon. The charge is taken in a molten state from the blast furnace to the converter, a practice which has been in general use in Sweden since 1857. The slow working and small charges which characterize the

TABLE VI-B.

Manganiferous Bessemer Pig-Irons.

Name of Works.	Sample.	Time to beginning of boil.	Time of blowing when samples were taken.	Composition of Metal; per cent.			Composition of Slag; per cent.			
				C	Si	Mn	SiO_2	FeO	MnO	Al_2O_3
Langhyttan.	Pig-Iron.	. . . .	. . . .	3.94	1.14	.64	. . .	. . .	. . .	. . .
	Bess. bath	2m. 45s.	2m. 15s.	4.20	.04	.12	48.76	34.72	13.95	.76
	" "	. . . . .	4m. 30s.	1.10	.06	.12	59.82	21.08	15.48	.98
	" "	. . . . .	5m. 30s.	.05	.01	.06	48.48	35.82	12.29	.72
Nykroppa.	Pig-Iron.	. . . . .	. . . . .	4.35	.88	1.15	. . .	. . .	. . .	. . .
	Bess. bath	1m. 30s.	2m. 30s.	4.10	.10	.15	53.26	13.50	29.76	2.28
	" "	. . . . .	5m. 30s.	1.00	.05	.15	62.94	9.54	23.70	3.99
	" "	. . . . .	6m. 30s.	.08	.04	.08	44.52	30.60	21.39	2.14
Westanfors.	Pig-Iron.	. . . . .	. . . . .	4.22	1.06	5.12	. . .	. . .	. . .	. . .
	Bess. bath	2m. 30s.	4m. 15s.	4.20	.43	3.26	45.67	4.20	46.38	3.06
	" "	. . . . .	8m. 35s.	1.80	.12	.85	39.07	6.94	52.36	2.49
	" "	. . . . .	9m. 20s.	.55	.07	.43	37.63	9.45	48.92	2.94

Bessemer practice of Sweden render necessary a hot-blowing metal, and since the silicon cannot be high without danger of leaving some in the product, it is customary to have from 1.5 to 4.0 per cent. of

* *Bessemer Process as Conducted in Sweden. Trans. A. I. M. E.*, Vol. XXII, p. 265.

manganese in the pig. Table VI-B gives analyses of metals and slags at different periods of the operation.

It will be seen that when manganese is present in large proportion, quite an amount is left in the steel after the boil has begun and even after most of the carbon has been eliminated. This will be illustrated by Table VI-C.

TABLE VI-C.

Steel from High-Manganese Pig-Iron.

Pig-Iron with 4 per cent. Mn and 1 per cent. Si.

Element.	Composition, per cent., of various heats.							
C	1.3	1.1	0.9	0.7	0.5	0.3	0.2	0.15
Mn . . .	0.6	0.55	0.5	0.4	0.3	0.2	0.15	0.12
Si	0.06	0.05	0.045	0.045	0.04	0.03	0.02	0.015

Pig-Iron with 5 to 6 per cent. Mn and 1 per cent. Si.

Element.	Composition, per cent., of various heats.				
C	1.3	1.1	0.9	0.7	0.6
Mn . . .	1.25	1.05	0.9	0.7	0.6
Si	0.25	0.2	0.15	0.12	0.1

SEC. VIe.—*History of the slag.*—Akerman discusses the part which the slag plays in the oxidation of the metalloids, but I have ventured to disagree with him on this point.* In the open-hearth process, the history of the slag is the history of the operation, for all the changes in the composition of the metal must be done through the mediation of the slag, but in the Bessemer the blast enters from the bottom and passes upward through the metal before it ever comes in contact with the slag. It is true that the charge is in a state of violent ebullition and that the slag is carried down into the metal, but such a mixing does not seem to be a necessary part of the operation, for, when the heat is first turned up, the silicon is immediately oxidized, although no slag is present. In short, the question resolves itself into a *reductio ad absurdum,* for it is the oxidation of the silicon which creates the slag, and hence the slag can hardly be necessary for the oxidation of silicon. The slag does automatically adjust its own composition, and will do so

* *Trans. A. I. M. E.*, Vol. XXII, p. 667.

even after the addition of large quantities of iron oxide, but with much less precision than in the open-hearth furnace.

In America, little attention has been paid in the past to the composition of the slag, as the proportion of manganese in the iron has usually been below 0.50 per cent. and the slag was thick and viscous. Within recent years the increased use of Mesabi ores has given a pig-iron carrying often 0.60 per cent. and sometimes over 1.00 per cent. of manganese. Such an iron causes much slopping during the blow, and gives a thin slag that makes it more difficult to properly recarburize the metal. Table VI-D gives the composition of slags from eight different Bessemer plants in America. Sample I was made from irons containing from 2 to 3 per cent. in silicon, while K was from irons running over 1 per cent. in manganese.

TABLE VI-D.

Composition of American Bessemer Slags.

	SiO_2	FeO	MnO
A	55.5	12.7	26.9
B	52.8	18 1	24.6
C	64.9	1 .7	9.6
D	65.8	18.5	11.7
E	62.0	16.9	12.1
F	59.7	19.3	12.0
G	62.2	20.3	11.7
H	55.5	23.0	18.0
I	69.5	15.3	9.4
K	47.0	10.1	35.5

The composition of the slag is sometimes changed by blowing with the vessel partly tipped over. This brings some of the tuyeres above the metal, so that the blast rushes over the surface, oxidizing considerable iron, and burning part of the CO to CO_2, so that there is a greater calorific development, and this method is taken to raise the temperature of a cold charge at the expense of a greater waste of iron, and a greater wear of the lining. Cold charges may arise from too low a content of silicon, from a low initial temperature, or from a newly repaired vessel. It is unusual in rapid American practice to have difficulty from insufficient heat, for the fastest plants will average eight heats per hour from a pair of 10-ton vessels, giving an output of 50,000 tons per month. Under these conditions one per cent. of silicon in the pig-iron is sufficient for the production of the necessary heat.

SEC. VII.—*Loss in blowing.*—When a Bessemer plant runs on cupola iron, the loss is usually 10 or even 11 per cent. With direct metal the loss is nearly 10 per cent., but in some places is stated to be as low as 8 per cent. Theoretically, there should be little difference in the loss between direct and cupola metal, for although silicon and manganese are lost in the cupola, these elements would be burned later in the converter at any rate, but by using direct iron it is possible to work with a lower content of silicon in the pig and thus reduce the loss. Assuming the minimum of 8 per cent., and assuming that the carbon, silicon and manganese do not amount to more than 5 per cent., there is a difference of 3 per cent. of metallic iron to be accounted for. Part of the metal enters the slag as shot, a separation by the magnet giving an average content of from 6 to 8 per cent., indicating a loss of about three-quarters of 1 per cent. of the total output, and this portion is a complete loss, as far as both product and heat are concerned. The large pieces of scrap in the vessel slag may be picked out by hand, and, as these are generally returned to the cupolas without reweighing, they are not reckoned in the percentage of loss. The smaller particles can only be recovered by the rather expensive process of crushing the slag and passing it over a magnetic separator.

Another portion of iron is chemically combined with the silica in the slag. Experiments at Steelton on a week's run gave 120 tons of vessel slag for every 1000 tons of pig-iron. This slag, after being cleaned with a magnet, averaged 15 per cent. of iron, representing a loss of 1.80 per cent. of the metal, but the pig-iron contained 1.75 per cent. of silicon, which is higher than necessary. With a content of 1.00 per cent., the weight of slag would have been less, but as the bottom and lining will wear about the same, the decrease in weight of slag with a decrease in silicon is not proportional. Adding together 0.75 per cent. of metal as shot and 1.8 per cent. as combined in the slag gives 2.55 per cent. against 3 per cent. lost, indicating that one-half of one per cent. is ejected from the nose in the form of dust and splashes. Some of the fine spray is oxidized outside the converter, but some is burned before it passes the nose; including what actually combines with the slag, about two per cent. of metallic iron is burned inside the vessel. This figure will be used in determining the heat evolved.

SEC. VIg.—*Calorific history of the acid Bessemer converter.*—Table VI-E gives a calculation on the calorific history of an acid converter. Given a bath of pig-iron at 1400° C. and air at 100° C., and the amount of heat required to heat the air to the temperature of the bath being allowed for, then the heat evolved by the union of the oxygen with the bath must be absorbed by the products of the oxidation. These products are steel, slag, oxides of carbon and nitrogen. The steel and slag will be raised to the final temperature of the bath; the gases will escape continuously, and, therefore, be heated to the average temperature in the case of nitrogen, or to an assumed three-quarters of the total rise in the case of oxides of carbon which come off during the latter half of the blow. The heat absorbed by the lining is approximated by assuming that a thickness of one centimeter (0.4 inch) participates in the increase of temperature. No estimate is made of heat lost by radiation.

The surplus heat, after allowing for heating the air, will be utilized in heating the steel, slag, gases and lining, while some is lost by radiation. The total surplus heat divided by the calorific capacity of the products at the average temperature of the bath (i.e., the heat required to raise their temperature 1° C.) will give the theoretical rise in temperature. The surplus heat credited to iron and carbon does not express their relative value, because the bath is relatively cold while silicon is being burned and comparatively hot while carbon is oxidizing, but the values used are theoretically accurate for calculating the rise in temperature. The end temperature is 1400+329=1729° C., omitting the loss due to radiation. This check on the rise in temperature will not exceed 50° C., which would leave the end temperature about 1679° C. and the actual rise about 279° C.

SEC. VIh.—*Direct metal.*—It has been the custom in Sweden to use the pig-iron melted from the blast furnace, while in other countries it was found, during the early history of the art, that it was better to remelt in cupolas. The success of the Swedish metallurgists arose partly from the necessity of saving fuel in a country where coal was not found, and partly from the favorable character of the native pig-iron, which, being made from charcoal, never contained high silicon, and was low in both sulphur and phosphorus. Moreover, a large proportion of the Swedish product is a hard steel, the blow being interrupted when the metal is high in carbon, and a

lower content of silicon is practicable. The manufacture of this hard steel is made feasible by the low phosphorus and low sulphur

TABLE VI-E.

Calorific History of the Acid Converter.

Data: 1000 kg. pig-iron; Si=1.00 per cent.; C=3.50 per cent.
Initial temperature=1400 C. Average temperature about 1600° C.
Loss=8 per cent. Metallic iron burned=2 per cent.
Specific heat at 1600° C., per cubic metre CO and N=0.40; CO_2=1.84.
Specific heat at 1600° C., per kilo liquid steel 0.21, liquid slag 0.25, lining 0.25; per kilo CO and N=0.32, CO_2=0.68.
Specific heat of air 100° C. to 1400° C., per cubic metre=0.346; per kg.=0.268.

NET HEAT DEVELOPMENT.

Combustion of Silicon—	Calories.	Surplus.
10 kg. Si+11.4 kg. O=21.4 kg. SiO_2=64,140		
11.4 kg. O=49.6 kg. air, absorbing		
49.6×0.268×1300	=17,280	46,860
Combustion of Iron—		
20 kg. Fe+5.7 kg. O=25.7 kg. FeO=23,460		
5.7 kg. O=24.8 kg. air, absorbing		
24.8×0.268×1300	= 8640	14,820
Combustion of Carbon—		
7 kg. C+18.7 kg. O=25.7 kg. CO_2=56,930		
28 kg. C+37.3 kg. O=65.3 kg. CO=68,600		
	125,530	
56 kg. O=243.5 kg. air, absorbing		
243.5×0.268×1300	=84,830	40,700
Total surplus heat developed.....		102,380

CALORIFIC CAPACITY OF THE PRODUCTS.

Weight×Sp. heat at 1600 degrees.		
920 kg. liquid steel×0.21		=193.2
150 kg. liquid slag×0.25		= 37.5
50 kg. lining	×0.25	= 12.5
25.7 kg. CO_2	×0.68×3/4	= 13.1
65.3 kg. CO	×0.32×3/4	= 15.7
244.8 kg. N	×0.32×1/2	= 39.2
Total capacity per 1° C.		=311.2

Theoretical rise of temperature $= \frac{102,380}{311.2} = 329°$ C.

in Swedish irons, and although interrupting the blow gives irregular results the steel can be graded after it is made. The failure of the direct metal process in other countries arose from irregular blast-furnace work. By allowing the iron to become cold and mixing the different qualities, it was possible to get a more regular metal. Direct metal is practicable to-day mainly because of im-

proved furnace practice, while difficulties are also avoided by having a large receiver, often called a mixer, into which is poured the melted iron from all tributary furnaces, and in which a mixing or averaging takes place. This receiver is an enlargement of the old American receiving ladle.

SEC. VIi.—*Cupola metal.*—The cupolas used in steel works measure from 6 to 8 feet internal diameter, while the height should be at least 20 feet. The fuel consumption varies, one pound of coke melting from 11 to 15 pounds of iron. The coke must be as free as possible from sulphur, as the iron, during melting, absorbs this element. With fast running and good coke, this absorption may be only .02 per cent.; with slow running and bad coke, the sulphur in the iron may be raised .20 per cent. in the cupola. About half of one per cent. of silicon and some manganese are oxidized during melting and also some metallic iron. This loss of iron can be found only by weighing and analyzing the cinder running from the tap-hole. An experiment of this kind on a 24-hour run, melting 400 tons of iron, showed a slag containing 8.77 per cent. of metallic iron, and a loss of iron representing 0.42 per cent. of the pig-iron charged. Other determinations showed a less percentage of iron in the slag.

SEC. VIj.—*Factors affecting the calorific history.*—Until within a few years, it was thought necessary to have from 2.0 to 2.5 per cent. of silicon in the metal as it entered the converter, but the general practice at the present time is to have from 1.0 to 1.5 per cent., although it is feasible to operate with a content of from 0.6 to 0.8 per cent. This reduction of calorific power has been made practicable by several small improvements:

(1) Fast running, the iron never standing long enough to cool, and the steel ladles and vessels always being hot.

(2) Quick blowing, the radiation from the vessel being decreased, and the time lessened during which the idle vessel is cooling.

(3) Good bottoms and linings, the scorified material being reduced, and delays for repairs avoided.

(4) Quick changes of bottoms, and less cooling of the vessels.

(5) Blowing with the vessel partly tipped over when the charge is cool, rendering less necessary an excess of heat-producing elements as a provision against delays or change of bottoms.

Ehrenwerth* argues that pig-iron low in silicon should give better steel, for, with high silicon, there is a greater proportion of free oxygen in the gases during the first stages of the blow. The percentage of carbon is nearly constant in all irons, and, with an increase in silicon, there is a corresponding increase in the proportion which the silicon bears to carbon. Granting that the presence of free oxygen in the gases escaping from the vessel during the first part of the process is due to the proportionately greater quantity of silicon as compared with carbon, then if the metal at the end of the operation should contain a high proportion of silicon as compared with its content of carbon, the escaping gases would contain free oxygen. This proportionately high silicon at the end of the operation is found in heats which contained a high initial percentage of silicon in the iron, and hence such heats would be expected to have free oxygen in the bases which are formed at the close of the operation, and this free oxygen will signify a more highly oxidized condition of the metal.

Notwithstanding that tipping the converter has rendered unnecessary as large a margin of calorific power as was formerly necessary, it is advantageous to have a slight excess of silicon to allow for delays and new bottoms, so that it is necessary to lower the temperature of normal charges by the addition of steel scrap or solid pig-iron. The skill attained in estimating the temperature of melted steel seems almost incredible to the lay mind, for it is possible to detect the difference caused by a variation of 100 pounds in the amount of scrap added to a 7-ton charge in the converter, and I have elsewhere† tried to show that this represents a difference of only 13° C. It must be acknowledged that all heats are not regulated to such exact measure, but a variation of three or four times this amount is more than is expected in current American practice. This accuracy can only be obtained by uninterrupted work, so that we find that the best "scrapping" follows the fastest running. This fact is an answer to the criticism of foreign metallurgists that the large outputs of American Bessemer plants have been made at the expense of quality. There is no evidence to show that an ample supply of air, and a shorter blow, will give an inferior product, but, on

* *Das Berg- und Huttenwesen auf der Weltausstellung in Chicago.* Ehrenwerth, 1895, p. 276.

† *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII. p. 392.

the other hand, the more rapid action renders possible a lower initial content of silicon, and this is an advantage.

SEC. VIk.—*Recarburization.*—The method of recarburizing in Bessemer practice varies with the character of the product. In making soft steel, solid ferro containing 80 per cent. of manganese is thrown into the ladle during pouring, the loss of metallic manganese being about 0.2 per cent. of the charge. With rail steel it is customary to add melted spiegel-iron either in the vessel or in the ladle. The loss of manganese depends upon the condition of the bath and upon the amount added. In making soft steel it is necessary to blow until the carbon is reduced to about .05 per cent., and, if manganese be added to the extent of .60 per cent. of the weight of the charge, the steel will contain .40 per cent., a loss of .20 per cent. If 1.30 per cent. be added, the steel will contain only .90 per cent., a loss of .40 per cent. It seldom happens that soft steel is wanted with over .60 per cent. manganese, but larger proportions are not unusual in rail steel. In the latter case it is feasible to economize by stopping the blow when the carbon is about .10 per cent., and, under these circumstances, an addition of 1.10 per cent. will give 0.90 per cent. in the steel. These figures are approximate, and represent what may be expected in the long run, rather than on any one heat.

CHAPTER VII.

THE BASIC-BESSEMER PROCESS.

SECTION VIIa.—*Outline of the basic-Bessemer process.*—The basic-Bessemer process consists in blowing air into liquid pig-iron for the purpose of burning most of the silicon, manganese, carbon, phosphorus and sulphur of the metal, the operation being conducted in a basic-lined vessel, and in such a manner that the product is entirely fluid. The method by which the air is introduced has little effect on the product, but the use of a rotary vessel with bottom blast is universal.

The distinctive feature of the basic vessel is a lining which resists the action of basic slags; this is almost always made of dolomite. The stone must be burned thoroughly to expel the last traces of volatile matter and then ground and mixed with anhydrous tar. The bottom is generally made by ramming the same material around pins which are withdrawn after firing. At one German works magnesite tuyeres are used which last seventy heats, but the cost is high and the practice has not been generally adopted.

The highest function of the lining is to remain unaffected and allow the basic additions to do their work alone, so that the rapid destruction of a basic, as compared with an acid lining, is not due to any necessary part it plays in the operation, but to the fact that there is no basic material in nature which, by moderate heating, will give the firm bond that makes clay so valuable in acid practice. The agent used in its place is a rich tar, and this forms a coke under the action of heat and resists the scouring of metal and slag, and, by the time this coke is burned, the dolomite has become partially fused and "set." There is always, however, a slight shrinkage in the burned stone, no matter how thoroughly it has been roasted, so that there is a tendency to self-destruction through the formation of innumerable disintegrating cracks.

When air is blown through pig-iron, the first element affected is

the silicon. This is true in both the acid and the basic processes, but the elimination is less certain in the acid process, for part of the silicon is sometimes left after the carbon is burned, if there has been an excessive temperature at an early stage of the operation. In the basic converter the incomplete combustion of silicon does not occur, owing to three reasons:

(1) The silicon is lower in the pig, because the oxidation of phosphorus is relied upon for heat.

(2) Burned lime is added before blowing, to seize the silica as soon as formed and prevent cutting of the lining, and the heating and melting of this lime absorbs so much heat that the critical temperature cannot well be reached.

(3) The basic slag has a greater affinity for silica than the silicious slag of an acid converter, and it is probable that under these conditions the critical temperature is raised.

When the silicon is eliminated, the carbon begins to burn and continues until there is only about .05 per cent., while the manganese follows the same course that it does in acid work, part of it being eliminated while the silicon is burning and another part during the combustion of carbon. The proportion of manganese at any particular time will depend upon the original percentage in the pig, but, comparing similar contents, the amount eliminated will be less than in the acid practice, for there is less demand for its oxide in a basic slag, and the inducements to oxidation are, therefore, taken away.

SEC. VIIb.—*Elimination of phosphorus.*—With the exception of the basic lining, which is supposed to remain inert, and the basic slag, which has no chance in the early part of the operation to do anything besides aid slightly in the burning of silicon and retard slightly the oxidation of manganese, the reactions in the metal in a basic converter are almost identical with the reactions in the acid vessel up to the point when the carbon is reduced to .05 per cent. From this point comparison ceases, for there the acid process ends, while the basic begins the characteristic chapter in its history in the elimination of phosphorus and sulphur.

In an acid heat phosphorus is present to a certain extent, and, if blowing were continued, it may be supposed that at the very surface of an air-bubble phosphoric acid would be formed which, rising through the metal, would unite with oxide of iron and form

phosphate of iron; but this would immediately come in contact with a silicious slag, or, in other words, with a slag possessing more than enough silica to meet the requirements of its bases, and the silica being immediately seized by the oxide of iron, the unprotected phosphoric acid would be robbed of its oxygen by the metallic iron. This may seem a long explanation of the simple fact that phosphorus does not oxidize, but there are reasons for supposing that in many chemical actions the atoms are in a state of general translation, so that while many compounds are formed, only those remain which find a suitable environment. It is difficult to explain the formation of phosphoric acid in the basic converter without assuming an action which can just as readily obtain in acid practice, although in the one case the product finds a resting-place, while in the other it is instantly destroyed.

During the elimination of carbon, a small quantity of phosphorus is burned and held by the slag, but for practical purposes the percentage at the drop of the carbon flame is equal to the initial content. From that time the phosphorus seizes the oxygen in the same way as the silicon and carbon had done before, and the iron is perfectly protected, the phosphoric acid immediately uniting with the lime. It might be supposed that any other base like oxide of iron would serve to hold the phosphorus, but phosphate of iron is easily reduced by carbon, and in other respects iron oxide is inferior to the oxide of calcium which gives a stable compound.

SEC. VIIc.—*Amount of lime required.*—The amount of lime needed will depend upon three conditions, viz.:

(1) The amount of silicon in the pig.

(2) The amount of phosphorus in the pig.

(3) The quality of the lime.

If the charge is 15,000 pounds, containing 0.50 per cent. silicon, it will produce 160 pounds of silica; and if the final slag must contain 6.0 per cent. silica, then the slag must weigh 2670 pounds; and if it must have 50 per cent. CaO, then 1335 pounds of *unsatisfied* CaO must be added. The qualification is inserted that it must be "unsatisfied," for each pound of silica in the lime detracts from its efficacy. Thus, if the lime contains 2 per cent. SiO_2, there will be 2 pounds of silica in every 100 pounds of addition, and if this is to be made into a slag containing 6 per cent. of SiO_2 and 50.0 per cent. of CaO, then 8 pounds of CaO is useless, since it will

be appropriated by its own silica. In this way, 10 pounds of the lime out of every 100 pounds is used in satisfying itself.

The silica derived from the lime and from the silicon does not entirely determine the quantity of lime, for there is a limit to the content of phosphoric acid in the cinder. Thus, if a bath of 15,000 pounds contains 3 per cent. of phosphorus, it will produce 1030 pounds of phosphoric acid, and if the final slag is to contain 50 per cent. CaO and not over 20 per cent. P_2O_5, then this slag must weigh $5 \times 1030 = 5150$ pounds, so that $\frac{5 \times 1030}{2} = 2575$ pounds of CaO must be added to the charge. It is not specified in this case that the CaO shall be "unsatisfied," for it will be immaterial what the silica may be in the lime, as long as the demands of silica are met.

SEC. VIId.—*Chemical reactions.*—The chemical history of the basic converter is shown in Table VII-A, which gives the analyses of metal, slags and gases at various stages of the operation, as given by Wedding. The high percentage of oxygen and carbonic

TABLE VII-A.

Metal, Slag and Gases from the Basic Converter.

Time from Beginning.	Metal.					Slag.						
	Si	C	P	S	Mn	SiO_2	CaO	P_2O_5	FeO	Fe_2O_3	MnO	MgO
Pig Iron No. 1	1.22	3.21	2.123	.080	1.03	. . .	. . .	. . .	. . .	. . . .	. . .	. . .
2m. 46s.	0.72	3.30	2.143	.047	.71	41.15	41.27	0.84	2.40	. . . .	9.08	4.13
5m. 21s.	0.15	3.12	2.224	.051	.50	36.50	39.50	3.12	3.97	0.46	11.02	3.39
8m. 5s.	0.007	2.47	2.157	.049	.18	34.41	42.80	2.99	3.60	0.13	10.72	3.35
10m. 45s.	0.012	1.49	2.006	.051	.16	31.94	43.12	4.02	4.28	0.74	9.94	4.01
13m. 28s.	0.005	0.75	2.058	.051	.14	16.64	44.37	7.15	8.42	4.95	8.51	7.34
15m. 13s.	0.008	0.05	1.910	.055	.01	14.65	46.63	11.60	7.15	3.84	7.39	6.34
19m. 14s.	0.005	0.02	0.230	.060	.01	12.94	47.76	18.88	5.84	3.74	4.25	6.00
19m. 31s.	0.005	0.02	0.139	.055	. .	12.20	48.59	18.66	6.79	2.80	4.01	6.28
19m. 49s.	0.004	. . .	0.087	.056	. .	11.71	48.19	18.15	7.19	2.78	4.05	6.38
Rail Steel,	0.01	0.26	0.145	.045	.48	12.77	47.87	16.92	5.94	2.87	4.80	6.75
Pig Iron No. 2	0.58	3.60	2.75	.079	1.57	. . .	. . .	. . .	. . .	. . . .	. . .	. . .
About 3m.	0.28	2.81	2.57	.079	2.50	9.20	76.10	2.94	0.55	. . . .	8.87	4.86
" 6m.	0.07	2.02	2.08	.073	0.30	9.50	71.40	6.90	0.73	. . . .	9.70	5.33
" 9m.	0.07	1.38	2.25	.074	0.34	9.20	66.17	7.32	2.20	. . . .	8.43	6.47
" 12m.	0.06	0.71	1.55	.079	0.26	10.28	50.71	15.37	7.13	. . . .	9.45	6.90
" 15m.	0.02	0.105	0.061	.054	0.21	6.99	46.84	24.73	11.98	. . . .	5.40	4.09
Steel,	0.02	0.136	0.084	.046	0.55	4.79	42.05	16.33	26.08	. . . .	4.62	6.83

Heat No. 862.	Metal.					Gas.				
	Si	C	P	S	Mn	CO_2	O	CO	CH_4	N
Sample 1	.28	2.81	2.57	.079	2.50	3.5	8.1	2.0	0.9	85.0
" 2	.07	2.02	2.08	.073	.30	8.0	8.0	10.6	1.0	81.4
" 3	.07	1.38	2.25	.074	.34	3.0	0.3	28.3	1.6	66.6
" 4	.06	.71	1.55	.079	.26	1.8	0.2	29.8	1.8	65.0
" 5	.02	.105	.061	.054	.21	1.2	0.8	1.6	0.9	95.6

acid in the gases during the first stage of the operation arises from the chilling action of the basic additions, for at low temperatures carbonic acid is not readily reduced by carbon, but as the metal becomes hotter the carbon assumes more complete command and appears almost entirely in the form of carbonic oxide. At the end of the blow, when phosphorus is burning, the oxygen is held in the bath and the only gaseous product is the nitrogen, so that when the combustion of phosphorus is ended there is no such sudden change in the character of the flame as marks the death of the carbon reaction, and in order to be sure of the purity of the metal it is necessary to make fracture tests on small sample ingots before the charge is poured from the converter.

SEC. VIIe.—*Elimination of sulphur.*—Sulphur is partly removed at the same time as the phosphorus, but, if in large quantity, it may be necessary to continue the blast after dephosphorization with the sacrifice of iron. This, however, is bad practice, and is far from being economical or desirable. In a series of heats made by the Pennsylvania Steel Company, in 1883, a content of 0.25 per cent. was reduced below 0.05 per cent. Manganese was

TABLE VII-B.

Reduction of Manganese from Slag in the Basic Converter.

(See *Journal I. and S. I.*, Vol. I, 1893, p. 63.)

Heat.	Time of taking test of metal.	Composition, per cent., of the metal in the bath.		
		Mn.	P.	S.
No. 184	Disappearance of spectrum line, At second lime addition,	0.19 0.62	2.070 0.468	0.188 0.067
No. 185	Disappearance of spectrum line, At second lime addition,	0.24 0.81	2.180 0.718	0.072 0.042
No. 186	Disappearance of spectrum line, At second lime addition,	0.24 0.79	2.890 0.488	0.081 0.047

present up to about 2.0 per cent., and this aids in the work, probably by the formation of sulphide of manganese. Even after the manganese has entered the slag it may be available for this function, for it can be reduced by the phosphorus and incorporated into the metal. Table VII-B is from a paper by Stead* to show the

* *On the Elimination of Sulphur from Iron. Journal I. and S. I.*, Vol. I, 1893, p. 61.

increase of manganese in the bath during a time when there was no addition of this element from outside the vessel.

The quantitative investigation of the basic converter is unsatisfactory, as some lime is blown out as soon as the charge is turned up, while at a later time a large amount of slag may be expelled by explosive action, this being particularly marked when the temperature is low. Moreover, the lumps of lime do not immediately become incorporated into the slag and no true sample can be taken. It is from these causes that contradictory statements are made by careful observers.

TABLE VII-C.

High-Sulphur Iron in the Basic Converter.

(See *Journal I. and S. I.*, Vol. I, 1893, pp. 61 and 62.)

Metal.	Composition, per cent.				
	Initial.	Desilicon-ized.	Decar-burized.	Dephos-phorized.	Steel.
Carbon	2.82	2.180	0.07	0.02	.....
Manganese	0.66	0.300	0.09	0.06	.....
Silicon	1.57	0.300	0.07	trace.	.....
Sulphur	0.16	0.148	0.16	0.08	0.07
Phosphorus	1.85	1.920	1.53	0.04	.....
Slag.					
CaO	.....	44.30	47.00	46.70	.....
MgO	.....	0.72	0.86	1.80	.....
MnO	.....	6.60	4.46	2.51	10.79
FeO	.....	4.33	8.23	14.02	9.00
Fe_2O_3	.....	1.29	1.00	4.20	2.14
SiO_2	.....	30.20	29.80	14.90	.....
P_2O_5	.....	2.61	7.83	14.86	.....
S	.....	0.16	0.10	0.26	0.26
Probable weight of liquid slag in per cent. of metal	.....	7	11	27	.....

Quantitative calculation on the Sulphur.

Sulphur in lime used, per cent. = 0.054 per cent.

Sulphur in Slag:	
27 per cent. of slag @ 0.26 per cent. S (see above columns) = per cent.	0.097
Less sulphur in lime added = 15.2 per cent. of 0.054 per cent. = per cent.	0.008
Total sulphur received from metal, per cent.	0.089
Sulphur removed from metal:	
100 parts of initial iron contained, per cent.	0.160
Less 85 parts of blown metal containing 0.080 per cent. S = per cent.	0.068
Total sulphur removed, per cent.	0.092

Wedding states* that there is a volatilization of both sulphur and phosphorus, as proven by the fact that the slags from sulphurous metal do not give correspondingly increased percentages of

* *The Process of German Metallurgy. Trans. A. I. M. E.*, Vol. XIX, p. 367.

CaS, while in the cinder from hot charges there will sometimes be from 30 to 40 per cent. less weight of phosphorus than was present in the pig-iron, although a cold blow will show the full amount. On the other hand, Stead* gives the figures for a basic charge where all the sulphur that was lost by the metal appeared in the final slag. The analyses and summary are given in Table VII-C.

It will be noted that the calculation rests on "the probable weight of liquid slag" for *one* heat, and this can hardly be considered a conclusive proof that volatilization cannot occur, or that it does not often occur, or even that it does not usually occur. In another chapter (see Sec. XIk) I have tried to show that such loss of sulphur may take place in open-hearth practice, and, if this is true, it seems probable that it will also hold good in the converter.

Some years ago it was the practice at two different works in Germany to add two-thirds of the lime at the beginning, so that when the metal was nearly dephosphorized the slag could be decanted, after which the rest of the lime could be put in and the final dephosphorization effected by a purer slag. The first cinder, which was rich in phosphorus and poor in iron, was fit for agricultural purposes, while the second, poorer in phosphorus and richer in iron, was used in the blast furnace.

This practice has been discontinued and at all works the total quantity of lime is added at the beginning of the blow. The final slag runs as follows, in per cent.: SiO_2, 5 to 6; CaO, 45 to 50; P_2O_5, 16 to 20; FeO, 11 to 13; MnO, 5 to 6; MgO, 5 to 6. In some cases the SiO_2 may be higher, but the P_2O_5 is then in a less soluble state, and the slag is not so well suited for agricultural purposes.

Sec. VIIf.—*Calorific equation.*—The calorific equation of the basic converter may be calculated by the same method that was used in the work on the acid process (see Table VI-F), but the great quantity of slag and the absorption of heat in its liquefaction render accurate results rather hard to obtain. The silicon is lower in the pig-iron, and consequently the heat derived from this source is less, but the phosphorus more than makes up for the decrease. In the calculation in Section VIf the net value of silicon per kg. was 4686 calories; of iron 741 cals.; of carbon 1163 cals., and, by the same method, we find that the value of phosphorus is 3821

* *On the Elimination of Sulphur from Iron. Journal I. and S. I.* Vol. I, 1893, p. 61.

calories. Assuming an iron with Si=0.5%, P=1.5%, C=4.0%, and assuming that 4.0 per cent. of iron is burned to useful purpose, the heat produced per 1000 kilos of iron will be as shown in Table VII-D, the total being about 50 per cent. more than in the acid converter.

TABLE VII-D.

Production of Heat in the Basic Converter.

5 kg.	silicon	23,430 calories
35 kg.	carbon	40,700
40 kg.	iron	29,640
15 kg.	phosphorus	57,315
	Total	151,085

The pig-iron for basic-Bessemer work should contain less than 1.0 per cent. of silicon, a content of 0.5 to 0.6 per cent. being not unusual. It should carry from 1.0 to 2.0 per cent. of manganese to assist in removing sulphur. The phosphorus, according to Harbord,* should be from 2.5 to 3.0 per cent., in order to have a margin of heat, but this assertion is probably based on English practice, as, in Germany, it is found that 2.0 per cent. of phosphorus is sufficient. The loss in the converter formerly ranged from 13 to 17 per cent. in different works, but now, in the best Westphalian plants, running on direct iron, it is as low as 10 per cent.

SEC. VIIg.—*Recarburization.*—Recarburization is the greatest problem of the basic-Bessemer process, for at the end of the operation the metal contains much more oxygen than an acid bath, while the slag, instead of being viscous and inactive, is liquid and has some loosely held oxide of iron. In making rail steel by the use of melted spiegel, this oxygen in metal and slag may give a reaction with the carbon of the recarburizer, and the carbonic oxide which is formed reduce some phosphorus from the slag. This action is shown in Table VII-A, where the phosphorus was raised in the case of "pig-iron No. 1" from .087 before recarburization to .145 in the finished product, the latter figure being too high for good rail steel.

When making soft steel by the addition of solid ferro-man-

* *Steel*, p. 90.

ganese the rephosphorization is less, but with bad practice it may be a troublesome factor. In "pig-iron No. 2," Table VII-A, the silicon is low in the pig, and the slag is rich in bases, yet the phosphorus in the metal was raised from .061 to .084 per cent., giving a content too high for the softest grades. The records in these tables relate to general practice some years ago, and can hardly be said to represent the best work to-day. Rephosphorization is now controlled by keeping the temperature as low as possible, by using a calcareous cinder, and by preventing the mixing of slag and steel during recarburization. This is done by decanting the slag before pouring the steel, and making a dam to hold back the remainder of the cinder. In going over the records of one of the best works in Germany and taking averages of large numbers of heats, the rephosphorization in rail steel was about .025 per cent. Five averages resulted thus, in each case the first figure being the bath before recarburization and the second the final steel: .044 to .070; .039 to .056; .036 to .062; .032 to .056; .043 to .070. In no case was there any charge where the resultant phosphorus was beyond the usual limit for rails. In soft steels the rephosphorization is less, owing to the less violent reaction, and the phosphorus content is lower than just shown in rail steel, but the variations, both in phosphorus and sulphur, are greater than in American open-hearth steel. The established American standards call for below .04 phosphorus in all basic steel for bridges and boilers, and every heat is analyzed for sulphur, something that is seldom done on the Continent. The foreign engineers are in no degree so exacting as the American in regard to chemical composition.

Note: Further remarks on the operation of basic converters will be found in Chapter XXIV.

CHAPTER VIII.

THE OPEN-HEARTH FURNACE.

SECTION VIIIa.—*Description of a regenerative furnace.*—The open-hearth process consists in melting pig-iron, mixed with more or less wrought-iron, steel, or similar iron products, by exposure to the direct action of the flame in a regenerative gas furnace, and converting the resultant bath into steel, the operation being so conducted that the final product is entirely fluid.

Regeneration is specified, because it is impracticable to obtain the necessary temperature in any other way. The construction of melting furnaces varies in every place, but in all of them the general principles are the same. Where natural gas is used, the fuel is not regenerated, but the air is always preheated. The following description will assume that both gas and air undergo the same treatment. In Fig. VIII-A is given a drawing of a common type of furnace; its faults will be discussed later, but it will illustrate the method of operation. The gas enters the chamber *F*, which is surrounded by thick walls and filled with brickwork so laid that a large amount of heating surface is exposed, while, at the same time, free passage for the gas is assured. The air enters a similar chamber, *E*. In starting a furnace, the bricks in these chambers are heated before any gases are admitted. With rich fuels, like natural gas, this may not be essential, but ordinary producer gas, when cold, can hardly be burned with air at the ordinary temperature, and an attempt to do so may result in serious explosions, so that it is advisable to heat the furnace by a wood fire until the regenerators show signs of redness. When, finally, the gas and air are admitted, precautions are taken to avoid explosions by filling the passages with the waste gases from the wood fire.

The first effect of their entrance is to cool the chambers on the incoming end, for no heat is produced until they meet in the port at *O*. From this point the flame warms the furnace and also the

chambers E_2 and F_2, through which the products of combustion pass to the stack. After the brickwork in the first set of chambers has been partially cooled by the incoming gases, the currents are reversed by means of suitable valves, and the gas and air enter the furnace by way of the chambers E_2 and F_2, which, as just stated, have been heated by the products of combustion. It will be evident that on every reversal the temperature of the furnace will be higher, for not only will there be the normal increment due to the continued action of the flame which would obtain in any system, but there is another action peculiar to a regenerative construction, for the gases passing through the chambers are hotter on every change in the currents and produce a more intense temperature in combustion. Thus the action is cumulative, and there is a constant increment of heat throughout the whole construction.

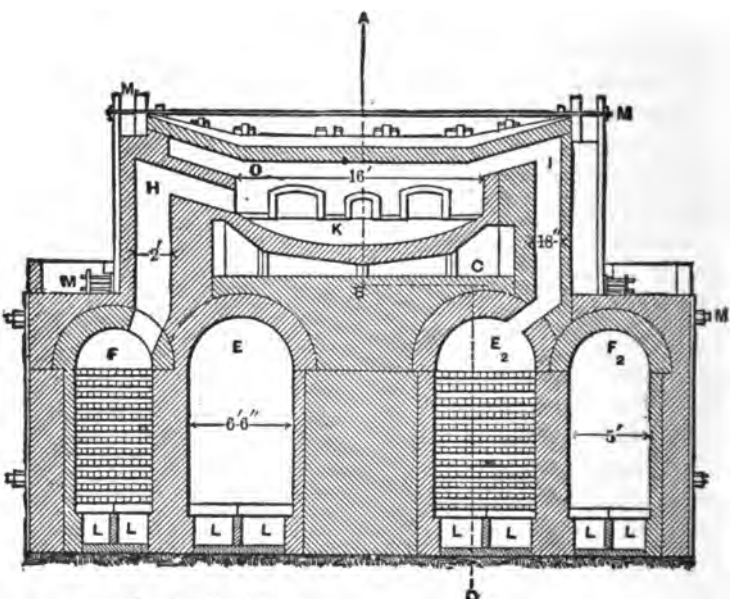
In the case of a furnace which has an insufficient supply of fuel and which contains a full charge of metal, the increased radiation at high temperatures may prevent the attainment of too high a heat; but in a good furnace the action is so rapid that the supply of gas and air must be carefully regulated, in order that radiation can maintain an equilibrium. This necessary control of temperature places a limit on the heat of the regenerators, so that they are usually at about 1800° F. (say 1000° C.). Dissociation plays no part in the operation, for, with common producer gas and air, both admitted to the valves at a temperature of about 60° F. (16° C.), the melting chamber may easily fuse a very pure sand into viscous porcelain. One such specimen of fused material showed the following composition, in per cent.: SiO_2, 98.82; Al_2O_3, 0.9; Fe_2O_3, 0.2.

SEC. VIIIb.—*Quality of the gas required.*—The system of regeneration, which supplies the furnace with a fuel already raised to a yellow heat, renders unnecessary any stringent specifications regarding the quality of the gas. Ordinary producer gas contains over 60 per cent. of non-combustible material, and yet is all that can be desired, as far as thermal power is concerned. Sulphurous acid and steam are objectionable, but rather from their chemical action upon the metal than from any interference with calorific development. Sulphur in large amounts causes trouble, as it is absorbed by the steel.

Steam gives rise to increased oxidation of the metalloids and a

greater waste of iron. This oxidation is not always objectionable, for, if the charge contains an excess of pig-iron, some agent must be used to burn the silicon and carbon. A gas containing hydrogen, like natural gas or petroleum, will be more efficient in this work than a dry carbonic oxide flame, while an excess of steam will make the action still more rapid; but its use is not to be recommended, for a considerable proportion of the oxide of iron will unite with the silica of the hearth and be lost beyond recovery. It is better to have no free steam during the melting of the charge, while, after the melting is done, the oxygen may be supplied in the form of ore with more satisfactory results.

The metal at the time of tapping should be as nearly as possible in the condition of steel in a crucible during the "dead melt," and this can only be attained by a neutral flame. In spite of the opinions of many metallurgists, such a flame cannot be obtained for any length of time, since it has no active calorific power, and even when black smoke is pouring from the stack, the silicon, man-



Longitudinal Section through Center of Furnace.
E, *E*$_2$, air chambers; *F*, *F*$_2$, gas chambers; *H*, gas port; *I*, air port; *K*, furnace hearth; *L*, flues to valves; *M*, *M*, binding rods; *O*, meeting place of gas and air.

FIG. VIII-A.—BAD TYPE OF AN OPEN-HEARTH FURNACE.

ganese, carbon and iron are absorbing oxygen from the gases. A carbonic oxide flame can be made more nearly neutral than any other, and hence is more desirable at the end of the operation.

SEC. VIIIc.—*Construction of a furnace.*—In the furnace exhibited in Fig. VIII-A the hearth sits partly upon the arches of the chambers. These arches, during the entire run of the furnace, are at a bright yellow heat and are subjected to strains and deformation by the alternating shrinking and expansion of the walls that support them. A poorer foundation for a furnace would be difficult to conceive, and some day there must be a long stop to make what are called "general repairs," this term being often used to cover the alterations consequent upon defective installation.

It is not easy to say just what the best construction is to avoid these difficulties. H. W. Lash, of Pittsburg, devised horizontal chambers, and thereby the charging floor of the furnace was brought down to the general level, and it was not necessary to elevate the stock. There are objections, however, to horizontal chambers, for the tendency of the hot gases is to seek the upper passages and the benefit of the full area is not secured. In vertical chambers, on the contrary, there is an automatic regulation of the current; for, if there is a hot place, the in-going cool gases naturally seek it, and if there is a cool place, the out-going hot gases find it, and there is a constant tendency to equalization and to the highest efficiency of a given regenerator content. The worst feature of horizontal chambers is the lack of any propelling action of the gases. With vertical regenerators the hot gas and air rise naturally and force themselves into the furnace, but with horizontal passages there is only a slight positive pressure due to the short up-take near the furnace. The fuel will and should leave the producer under a slight pressure, so that it will need no further assistance on its way to the furnace, but it is advisable to force the air with a fan-blower.

The room necessary in a regenerator is something on which there is great difference of opinion, but a much larger amount is economical than is generally given. If the chambers are large enough, all the heat can be intercepted, and the gases will go to the stack at the temperature of the incoming gas and the incoming air, but this would be carrying things to an extreme. The gases should not be at a red heat, although a very large number of furnaces are running with fair fuel economy where the gases, during

most of the melting operation, escape to the stack, showing a dull red or a full red temperature.

The space occupied by the air and gas checkers combined should be at least 50 cubic feet per ton of steel in the furnace, while to get the best results this figure should be at least doubled. In other words, in a 50-ton furnace the checker bricks in each chamber should occupy at least 2500 cubic feet, which is equivalent to a space 16'x16'x10', while, if they occupy a space 20'x20'x12', there will be a saving in fuel. These dimensions do not include the space below the bricks to give draft area for the gases, nor the space above the bricks to allow the flame to spread over the whole surface of the chamber.

In the 40-ton Steelton furnace, in Fig. VIII-B, the volume occupied by the air checkers is about 45 feet per ton; the gas chamber is less, so that the total is from 65 to 70 feet for both chambers. The double passage, however, allows a better absorption than would be given by the same volume in one mass. In the 50-ton Steelton furnace in Fig. VIII-C the total checker volume on one end is about 100 feet; in the 30-ton Donawitz furnace in Fig. VIII-D about 110 feet; in the 50-ton Duquesne furnace in Fig. VIII-E about 55 feet, and in the 50-ton Sharon furnace in Fig. VIII-F about 90 feet.

In another open-hearth plant the gas checkers on each end occupied 17 cubic feet per ton of steel and the air checkers 32 cubic feet. The products of combustion passing to the chimney from this furnace were red hot during a portion of the operation.

The information just given is by no means sufficient in stating merely the space occupied by the bricks, for it is fully as important to know the space left between them for the passage of the gases. The area of these channels must be far in excess of the area of the ports or of the flue leading to the chimney, since the friction caused by the small passages will retard the flow of gases, and this retardation will increase continually during the running of the furnace owing to the deposits of dust in these passages, decreasing the size of the orifices and forming a rough surface for the current to pass over. For this reason the sum of the area of all the passages between the bricks must be several times as great as the size of the flues and ports. The area between the bricks will in great measure determine the life of the checker bricks, for these bricks must be

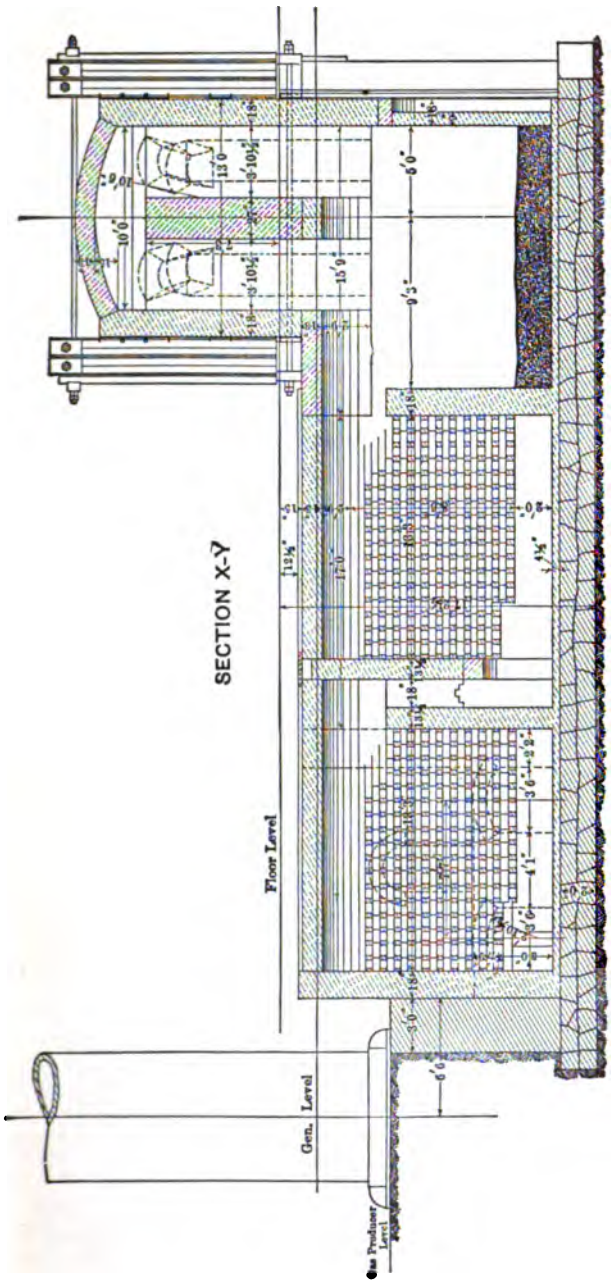


FIG. VIII-B.—40-TON ACID FURNACE, STEELTON, PA.

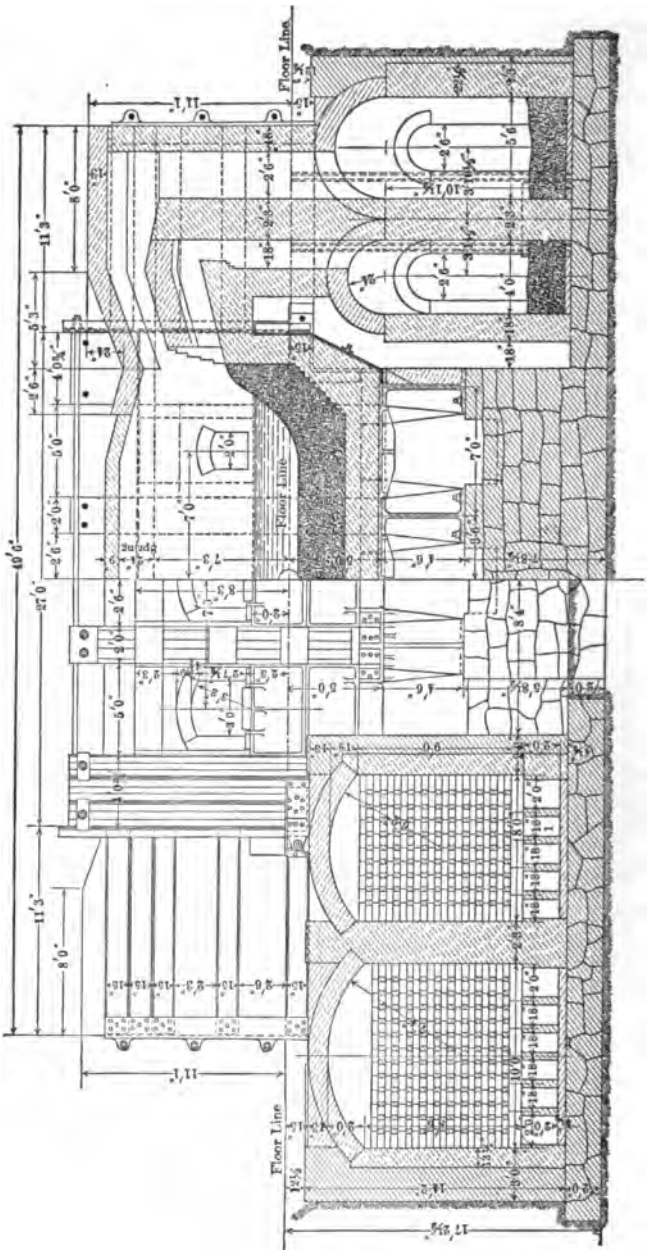


FIG. VIII-B.—40-TON ACID FURNACE, STEELTON, PA.

changed when the passages are clogged with dust. On the other hand, the loss of heat will also depend on these areas, for with larger orifices the gases will go through the checkers and to the stack without giving up their heat to the bricks, so that furnacemen must arrive at a compromise between large openings to allow long life to the checkers, and small openings to allow proper absorption of heat. There is also a third consideration, which is to arrange the bricks in such a way that they present the maximum area of heat absorption with the least interference with the passage of the gases, and with the least opportunity for the deposition of dust on horizontal surfaces.

The air chamber should be larger than the gas chamber, because a cubic foot of gas requires more than a cubic foot of air to attain

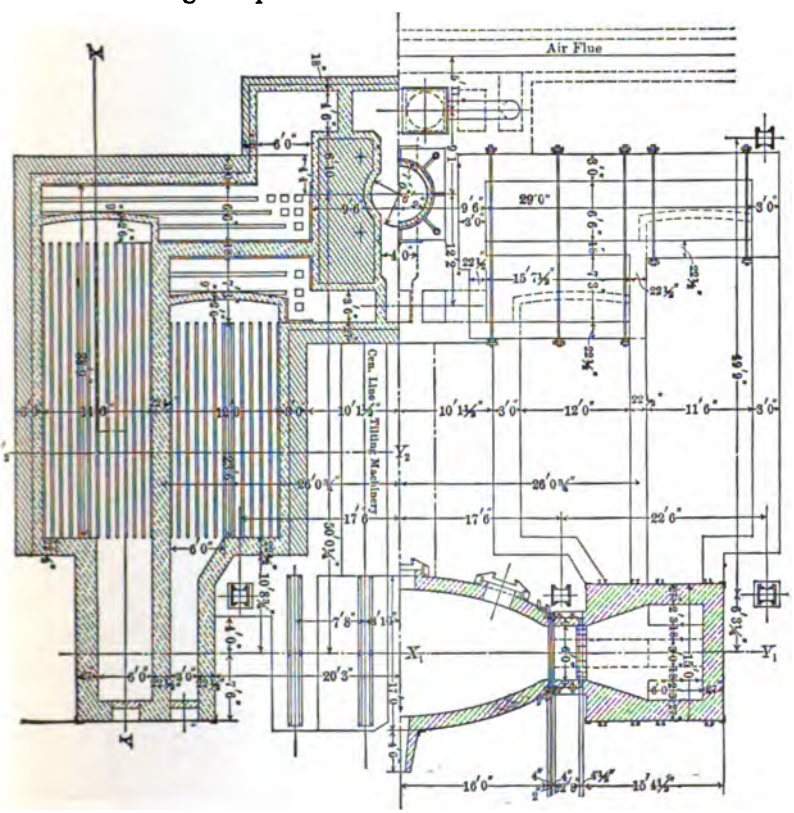


FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.

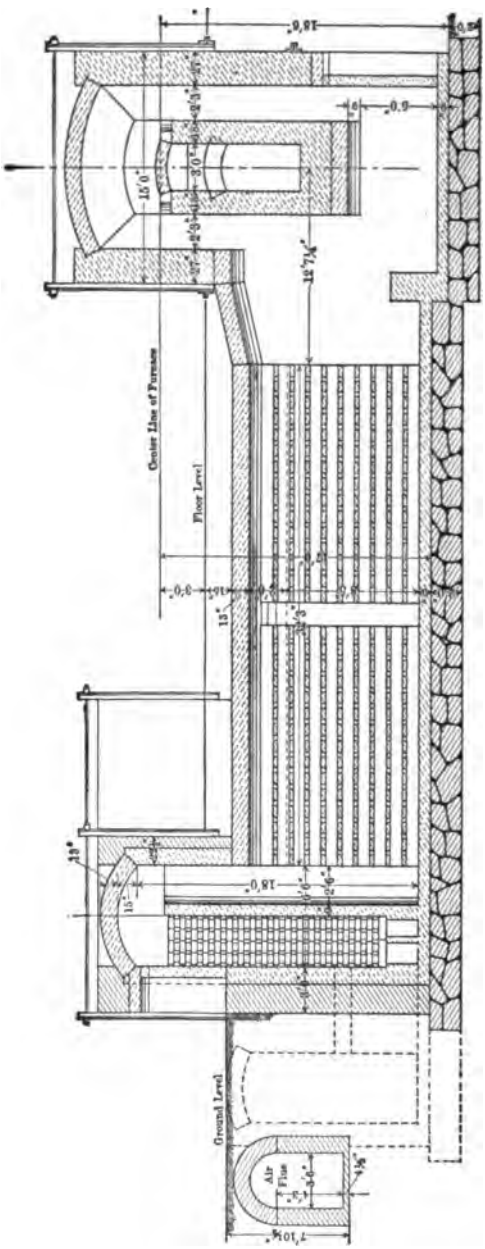


FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.

complete combustion and to have a slight excess of oxygen; moreover, the air enters cold, while the gas is generally warm; but in practice the relative volumes of the gas and air chambers will usually be determined more by the difficulties of getting room than by nice calculations on the volumes of gases. It is well, however, to keep the principle in mind that if the gas is hot there is less work for the gas chamber to do, and the fact that the gases escaping to the chimney are at a high temperature has nothing to do with the case, for if the entering gases are hot the escaping gases must be hotter. With a given sized chamber, the escaping gases will be just a certain number of degrees hotter than the gases that go into it. If this difference is 300°, then if the entering gas is 400°, the escaping gases will be 700°, and if the entering gases are 700°, the outgoing gases will be 1000°, so that it would be useless to increase the size of the chamber just because the outgoing gases are hot, for these conditions are caused by hot entering gases, and the escaping products would be hot no matter how large the chamber might be. Different melters have different ideas as to how a furnace should be run, and it is sometimes better to let them have their own way than to change the practice radically to accomplish a small saving. One melter may do better work if the air is extremely hot, while another may prefer that the air be colder than the gas. These differences also arise from the particular construction of ports, so that if an attempt is made to change the relative temperature of the chambers, it might necessitate a change in the construction of the ports and the roof of the furnace.

Under such circumstances the most practicable thing to do is to run the temperatures of the chambers in accordance with the construction of the ports and the roof. These conditions will oftentimes make considerable difference in the relative amounts of heat delivered to the gas and air chambers, and, therefore, will determine the relative size of the two chambers, and this may account for the difference of opinion concerning the proper area for the regenerators.

In the Schönwalder construction, introduced abroad, the main point is to have large flues underneath the checkers, so as to insure free draught in all parts of the chamber, so that the hot gases will go down and the cold gases come up, equally over the entire horizontal cross-section. To make more certain, the chamber is divided

into two compartments by a vertical wall, and separate flues run from the valve to each. The results indicate that a saving of fuel follows this construction. It often happens that it is impossible to build a furnace exactly as desired. This was the case in Figs. VIII-B and VIII-C, for permanent water existed only fifteen feet below the general level, and it was difficult to get sufficient room for checkers. In this case the air is blown by a centrifugal fan, the pressure being very low.

Fig. VIII-D shows the method of construction for basic furnaces at Donawitz, Austria, where the practice is excellent both in life of furnace and amount of product. Fig. VIII-E shows the 50-ton basic furnaces at Duquesne, Pa., and Fig. VIII-F those at Sharon, Pa. The drawing of the Duquesne furnace shows how the capacity of the chambers may be decreased when natural gas is used, as both regenerators are available for heating the air.

SEC. VIIId.—*Tilting open-hearth furnace.*—Many years ago I put in operation the first tilting open-hearth furnace, while a few years afterwards Mr. Wellman built a similar furnace, but used a different system of tilting. In the original type the furnace sits on live rollers running on circular paths; the center of these circular arcs is coincident with the center of the port through which the gas and air enter the furnace, so that the opening in the end of the furnace coincides with the port opening, no matter what position the furnace may occupy, and for this reason there is no occasion to cut off the gas and air when the furnace is rotated. In the Wellman type the furnace rolls forward upon a horizontal track and it is necessary to shut off the gas and air as soon as the furnace is tipped from its normal position.

I have often been asked to compare the relative advantages of these two types, and although evidently I cannot render a judicial and unbiased judgment, it may be proper to express my opinions, whether they be judicial or not.

(1) Both types of tilting furnaces do away with most of the work and delay connected with the tap-hole, and when the bottom is good the next charge can be put in as soon as the metal is tapped.

(2) If the bottom is bad, especially when there is a hole in the flat, a stationary furnace is often delayed by the tap-hole. In a tilting furnace of either type a hole can be drained dry by tilting the furnace and repaired in that position.

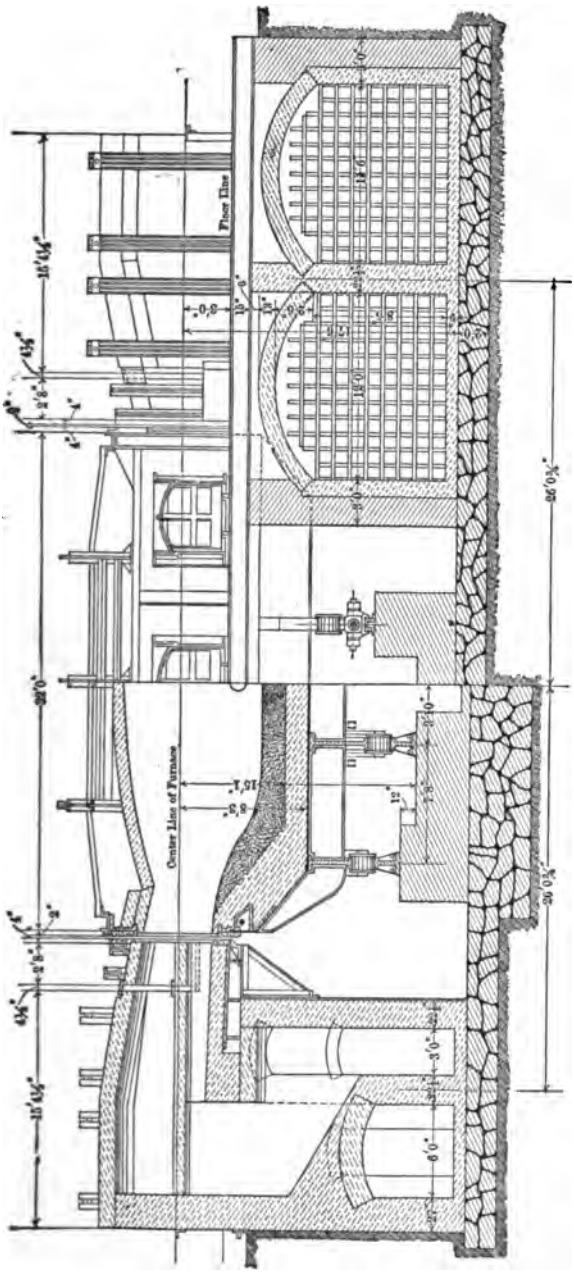


FIG. VIII-C.—50-TON CAMPBELL BASIC FURNACE, STEELTON, PA.

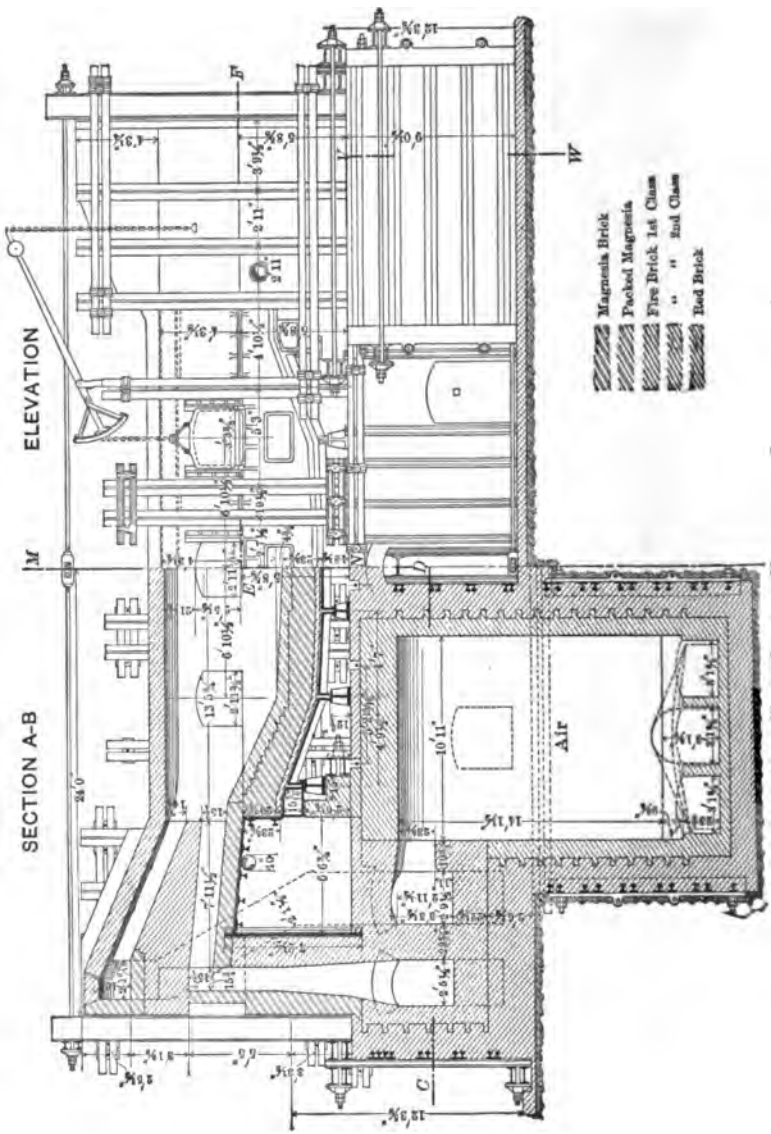


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

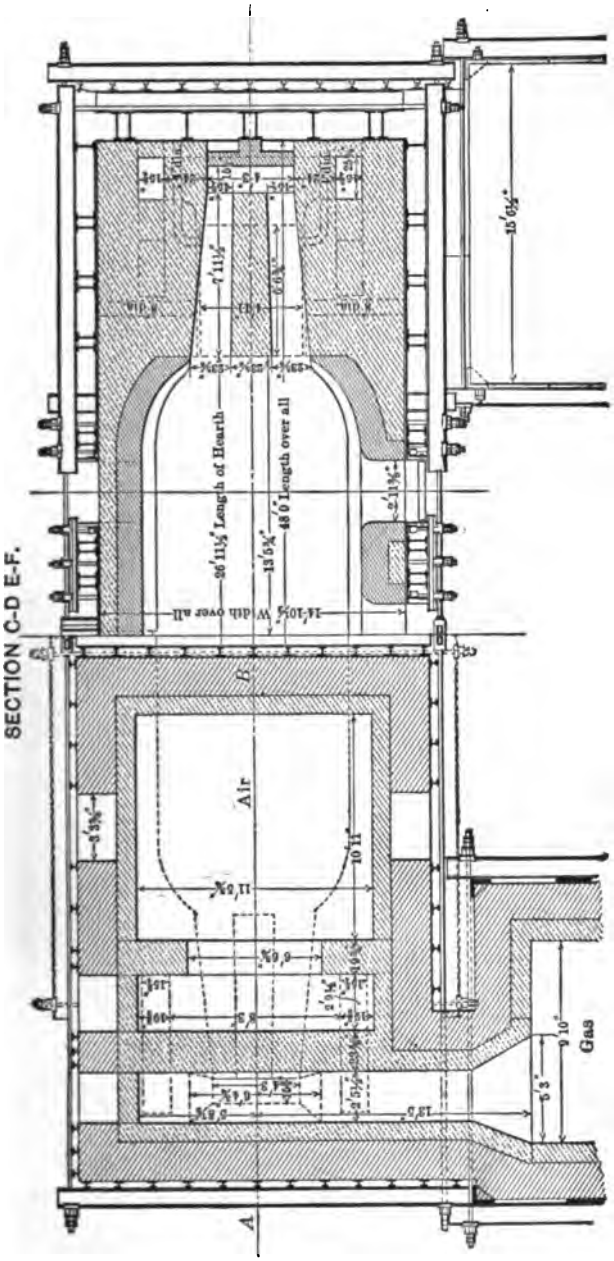


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

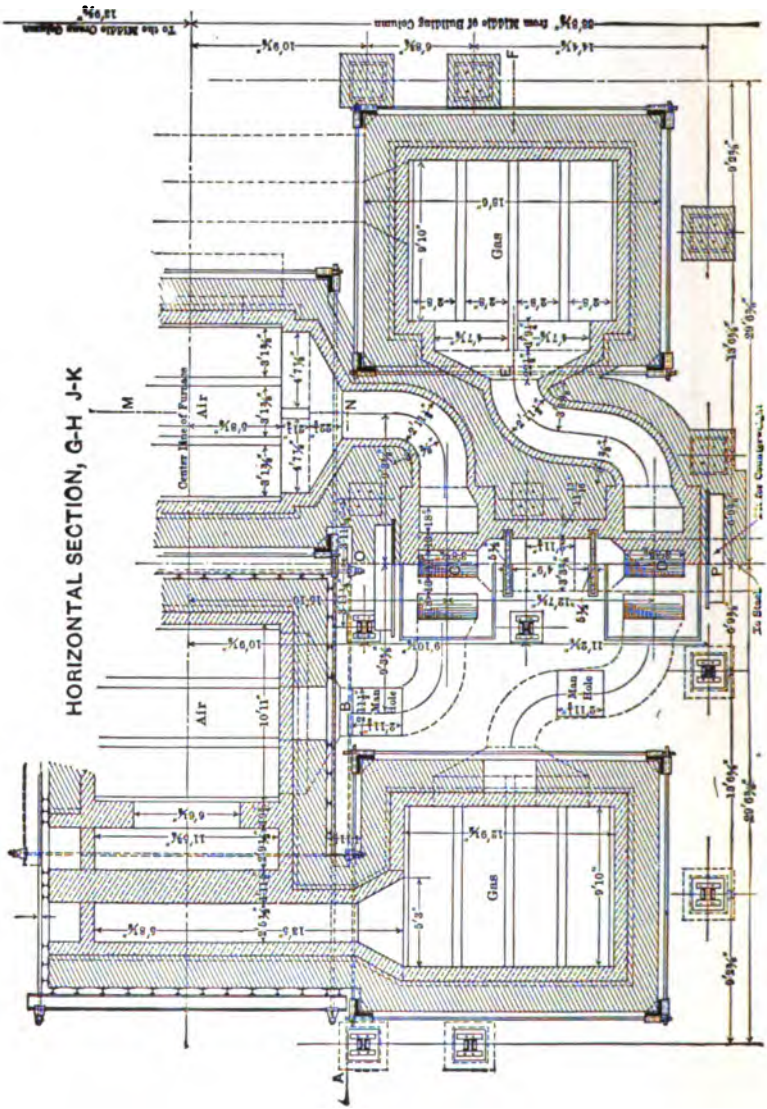


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

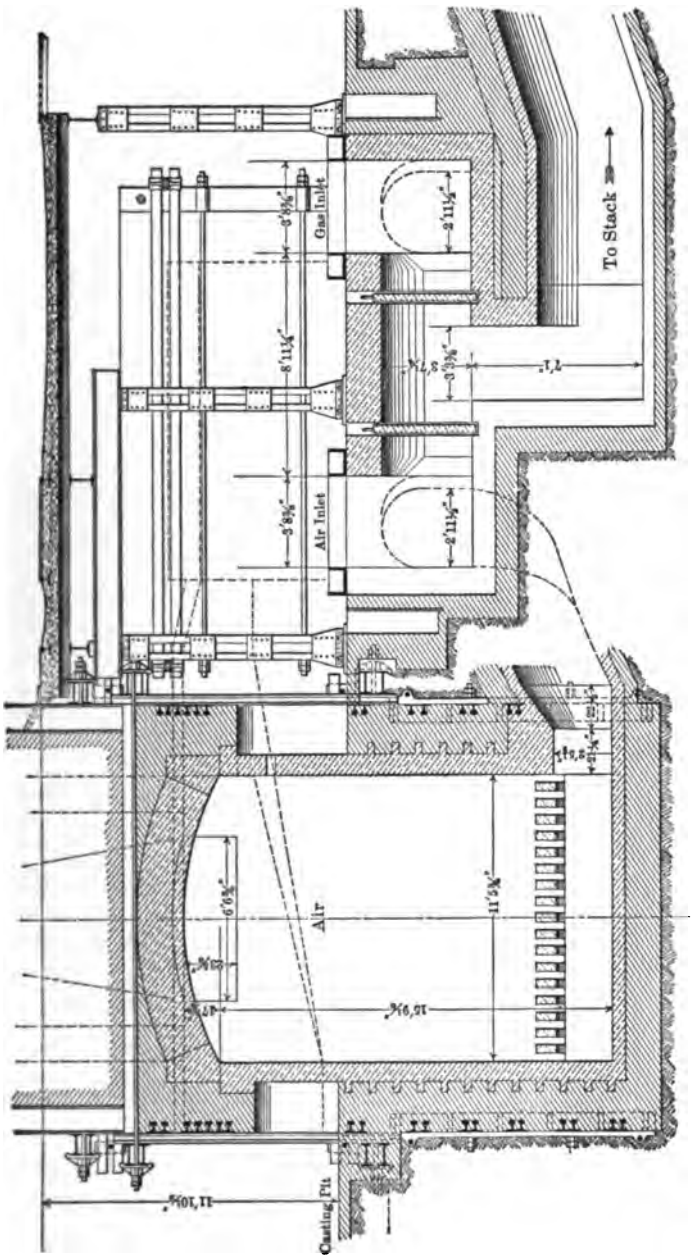


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

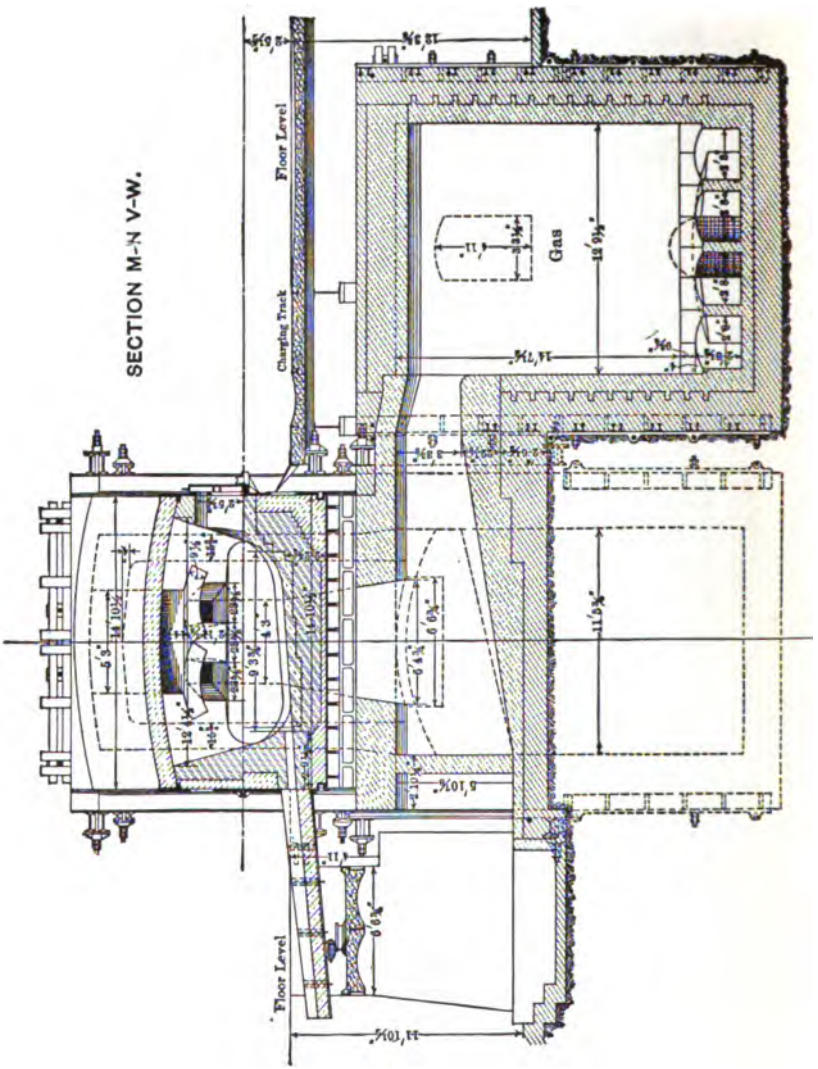


FIG. VIII-D.—30-TON BASIC FURNACE. DONAWITZ, AUSTRIA.

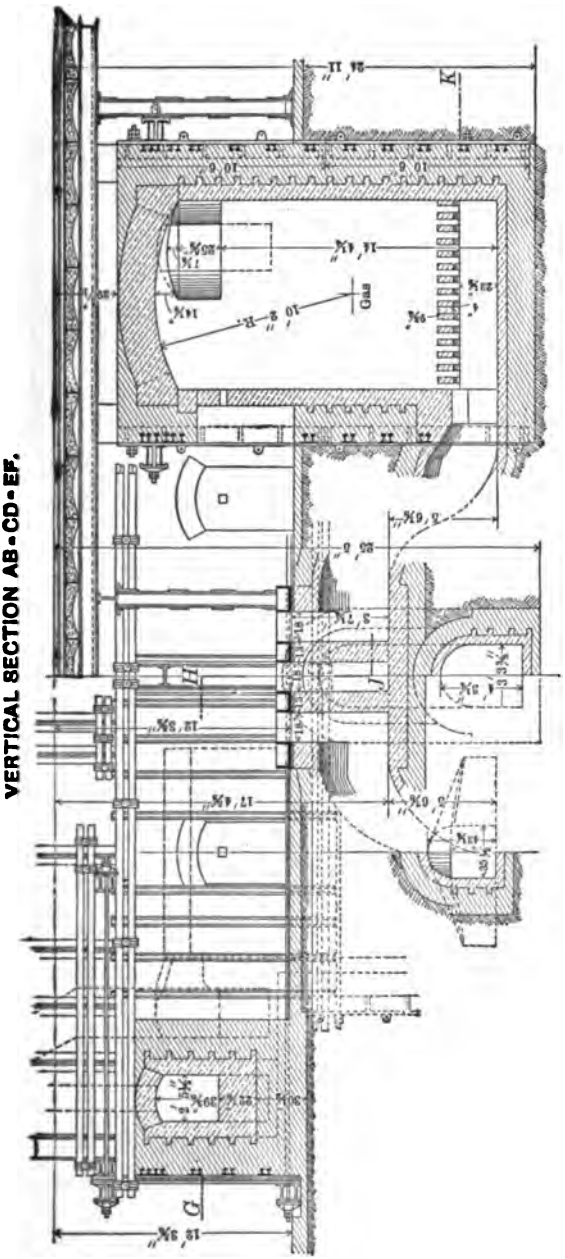


FIG. VIII-D.—30-TON BASIC FURNACE, DONAWITZ, AUSTRIA.

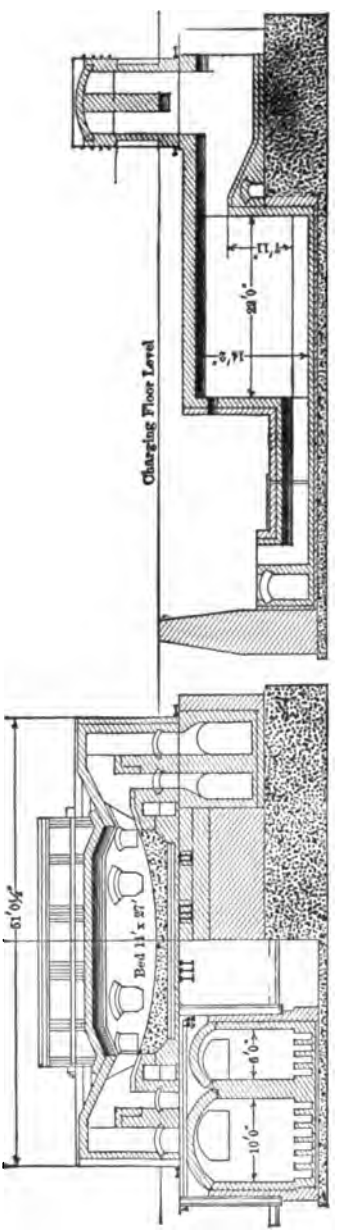


FIG. VIII-E.—50-TON BASIC FURNACE AT DUQUESNE, PA.

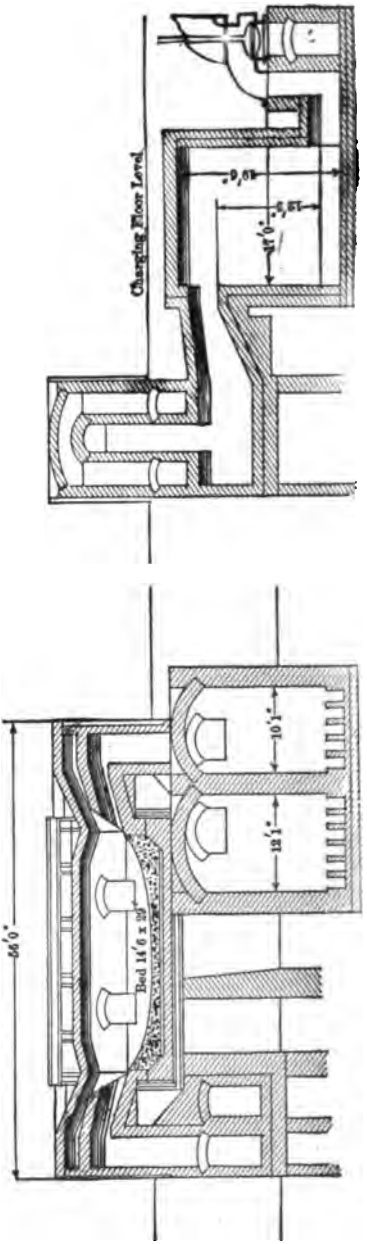


FIG. VIII-F.—50-TON BASIC FURNACE AT SHARON, PA.

(3) It is possible to make the back wall, in either type, by tilting the furnace to its extreme position and throwing bottom material on the back side, for this wall, which is nearly vertical during the regular operation, becomes more nearly horizontal when tipped over.

In the foregoing points both tilting types share, but the original furnace has certain important advantages.

(4) The back wall can be made more readily in the Campbell type, for in the Wellman construction no gas can be kept on the furnace when it is tipped, while in the first construction a flame is kept constantly going through. The setting of a sand bottom requires an extremely high temperature, and it would be impossible to set sand on the back wall without raising the furnace to its full temperature. It would, therefore, be impossible to do this in a Wellman furnace, while it has been done regularly at Steelton. In a basic furnace the Wellman furnace is able to coke and harden a tar mixture in place by the heat of the walls and bottom, but the work must be less satisfactory than in a furnace where the flame can immediately be put upon the dolomite and the coking be done quickly, and the furnace be heated for the next charge, instead of being cooled by exposure.

(5) Owing to the ability to build the back wall in this manner a steep slope can be maintained, much steeper than can be kept in a stationary furnace. If a vertical wall could be maintained at the slag line, the action would be reduced to a minimum, because it would be impossible for pieces of ore or scrap to lodge anywhere, and because the area of the surface exposed to slag would be less.

(6) The wear on the front or charging side is the same as on any other furnace, and there is the same liability to form holes along the slag line, but in the Campbell type such a hole is seldom a serious matter, for while the charge is in the furnace, and without interrupting the operation, the hearth may be tilted, the hole drained dry, filled with bottom material and set in the usual manner, after which the furnace may be returned to its proper position with practically a new bottom. Such repairs would be impossible with the Wellman type.

(7) The most important advantages arising from the ability to tip the furnace without altering the flame comes in the use of

large quantities of pig-iron. At Steelton we have antedated all others in America in the regular use both of melted and cold pig-iron as the full charge in a basic furnace, for we began using melted pig-iron directly from the blast furnace in 1891, it being recognized at the time that we were merely repeating what had been done a generation ago across the water. Three years later we ran two or more 50-ton furnaces on cold pig-iron without scrap, and from time to time, as the limited supply of iron for distribution to the Bessemer and open hearth would allow, we used the iron in a melted state. It was from about 1896 that melted iron was regularly and continuously taken from the blast furnaces to the open-hearth plant, from two to four 50-ton furnaces having been run regularly in that manner from then until now.

This has been done before, and is done elsewhere, but it is believed that nowhere else has iron been worked directly from the blast furnace without the use of a receiver, with silicon varying from 0.50 up to 3 per cent. and with no prohibitory trouble from frothing or from loss of time. This trouble is avoided by the ability to tip the furnace and prevent the metal and slag from flowing out of the doors on the front side, there being no doors on the tap-hole side, the excess of slag being provided for by holes left in the bottom of the port opening. Any hole or runner in a door or in the side of the furnace gives trouble from the chilling of the slag if the stream is small, and if the stream is large there is pretty certain to be some metal lost through the opening, but by having the opening located in the port, at the joint between the fixed end and the rotating portion, the opening is exposed continually to the flame passing over it in either direction and the slag has no chance to cool. If it should solidify, the crust can be broken by moving the furnace in either direction, thereby tearing apart the slag and starting the stream again. It is in this manner that the practice has been carried on at Steelton, and the melters soon learned without instructions to keep the furnaces partly tipped over throughout the whole period of the violent frothing, thereby rendering possible the rapid addition of ore.

(8) In an article on tilting furnaces by A. P. Head* he states that one of the objections to tilting furnaces is this:

"The inlet of cold air during pouring tends to oxidize the man-

* *Journal I. and S.*, Vol. 1899.

ganese, which must be made up for by further additions in the molds."

The objection is his own, made after a study of the Ensley plant of Wellman furnaces, and does not in any way apply to the original type.

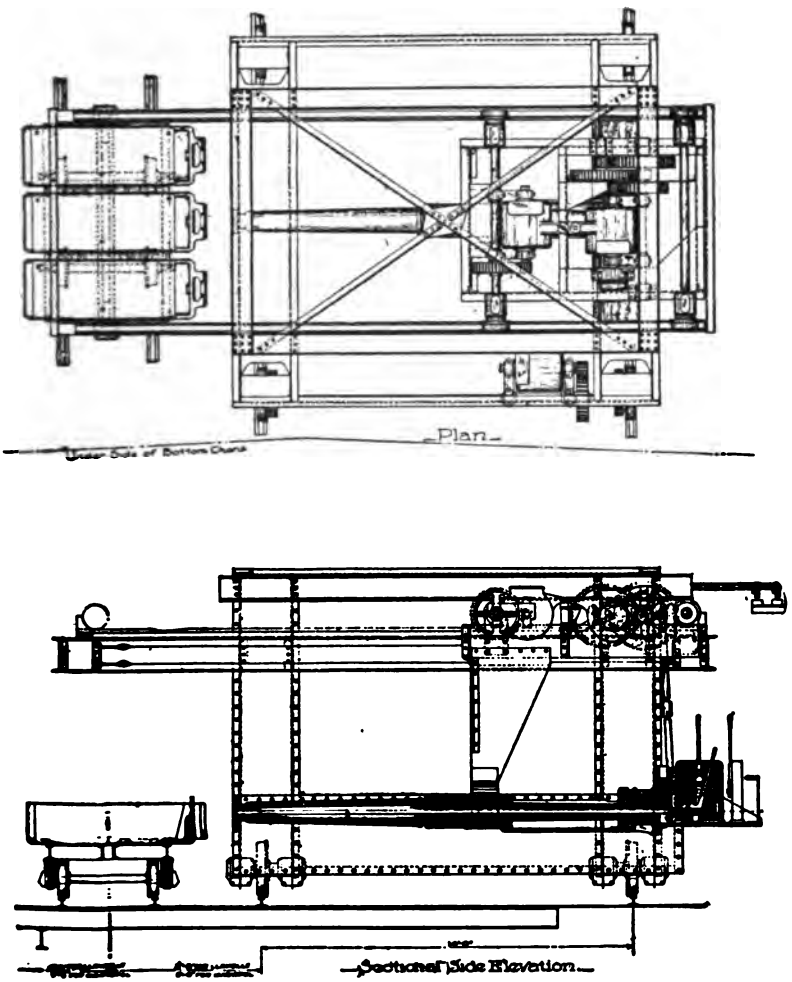


FIG. VIII-G.—WELLMAN CHARGING MACHINE.

SEC. VIIIe.—*Charging.*—The use of charging machines is now almost universal in America; one of the most common types is

shown in Fig. VIII-G. It is not uncommon for large works to have one or more furnaces so arranged that the entire top of the furnace is removable, thus giving an opportunity to dispose of heavy sculls and pieces that cannot easily be broken, but the furnace cools so much during this process of taking off the roof that considerably more fuel is used than in the ordinary types, and the roof does not last as long, owing to the severe strains in cooling and heating.

SEC. VIIIf.—*Ports.*—The working of the furnace depends very much upon the arrangement of the ports through which the gases come and go. The gas should enter below the air, because, being lighter, mixture is facilitated, and because this arrangement does not expose the metal on the hearth to a stratum of hot air and cause excessive oxidation. The point where the two gases meet should be about five feet from the metal; if much less than this, combustion can hardly begin before it is checked by contact with the cold stock; if much more, and if the burning mixture is conducted between confining walls, the brickwork will be melted. Both gas and air should enter the combustion chamber under a positive pressure, forcing them into contact with each other and throwing the resultant flame across the furnace in such a way that the draught of the stack on the outgoing end can pull it down through the ports without its impinging upon the roof. A prevalent idea among furnacemen is that the draught of the stack pulls the gases into the furnace; but this is entirely wrong. They are not pulled; they are pushed in by the upward force of the white-hot vertical port on the incoming end, and where this force is not sufficient, as in horizontal chambers, a blower should be used as an auxiliary.

The figures in Sec. VIIIc will show the different ways in which the port question has been answered. In Fig. VIII-C the portion of the construction next to the furnace is a removable cage containing the arch that divides the gas and air. When this arch is worn back this section can be removed by a crane and replaced by a new one, the whole operation not taking over one hour, and not interrupting the operation of the furnace. This system is the device of C. E. Stafford. The drawing of the furnace at Duquesne shows how simple the problem becomes when natural gas is used.

SEC. VIIIg.—*Valves.*—The amount of gas and air admitted to the chambers is regulated by some form of throttle valve. Revers-

ing apparatus is also necessary, since the course of the currents must be changed at least twice every hour. For this purpose the ordinary butterfly valve is in common use. Its simplicity, the ease with which it is manipulated, the small space it occupies, and its small first cost, have led to its general adoption and to a general unwillingness to recognize its irremediable defects. It is exposed on

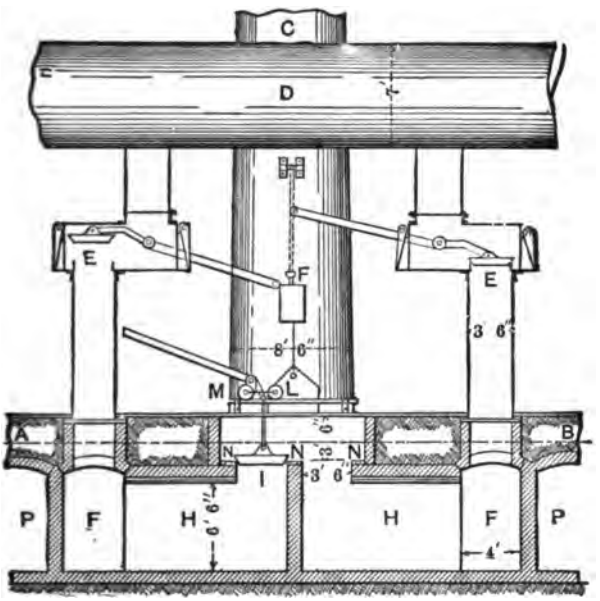


FIG. VIII-H.—REVERSING VALVES AT STEELTON.

Vertical Section Through Gas Reversing Valve.

C, stack; *D*, main gas tube; *E*, *E*, branch gas tube, showing valve; *F*, *F*, gas chambers; *H*, *H*, gas chamber flues to reversing valve; *I*, stack reversing valve for gas; *L*, stack damper for gas; *M*, valve reversing track and buggy; *N*, *N*, water-cooled valve seats: *P*, *P*, air chambers.

one side to the incoming gases, and on the other to the products of combustion. It will sometimes happen that these waste gases are red hot, and the inevitable result is a warping of the valve or box, and a leak from the gas main into the chimney. There is no adjustment possible, and the only remedy is to replace the whole outfit.

Fig. VIII-H shows a system of valves which has been used at Steelton with good results for a number of years, whereby the gas

inlet valve and the reversing valve are separate and the inlet valve is removed from all exposure to heat. This system was devised more especially for oil gas or where crude oil was the fuel, since under these conditions it is necessary that the chambers at the outer end should be at a high temperature in order to maintain the oil in a state of vapor. This necessitates a high temperature throughout the whole length of the chamber and an ordinary valve will not stand this temperature without excessive leakage and warping.

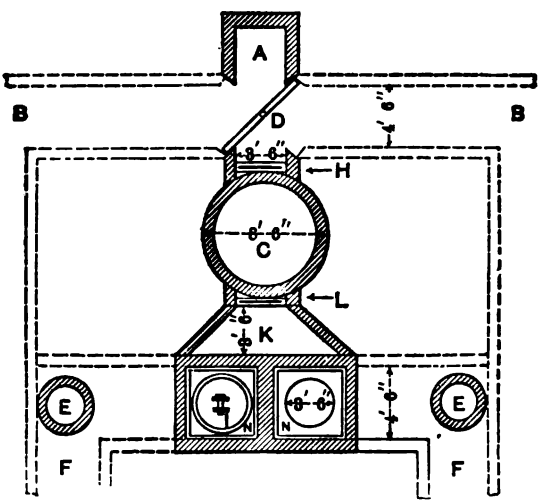


FIG. VIII-H.—REVERSING VALVES AT STEELTON.

Horizontal Section.

A, air inlet; *B*, *B*, air chambers; *C*, stack; *D*, air reversing valve; *E*, *E*, gas inlets; *F*, *F*, gas chambers: *H*, stack damper for air; *I*, stack reversing valve for gas; *K*, flue from reversing valve to stack; *L*, stack damper for gas; *N*, *N*, water-cooled valve seats

Such a complicated arrangement is not necessary with coal gas if the chambers are of sufficient capacity. A perfect valve should not warp if it gets hot, and should not leak if coated with tar or soot, and should not shut up by an accumulation of soot. No valve fills all these conditions, but Fig. VIII-I shows a Forter valve, which is, perhaps, as good as any in being easily manipulated and simple in construction. It is open to the objection that the gas is exposed to water and carries a great deal of steam into the furnace.

SEC. VIIIh.—*Regulation of the temperature.*—The temperature of the interior of the furnace and of the metal is estimated by the

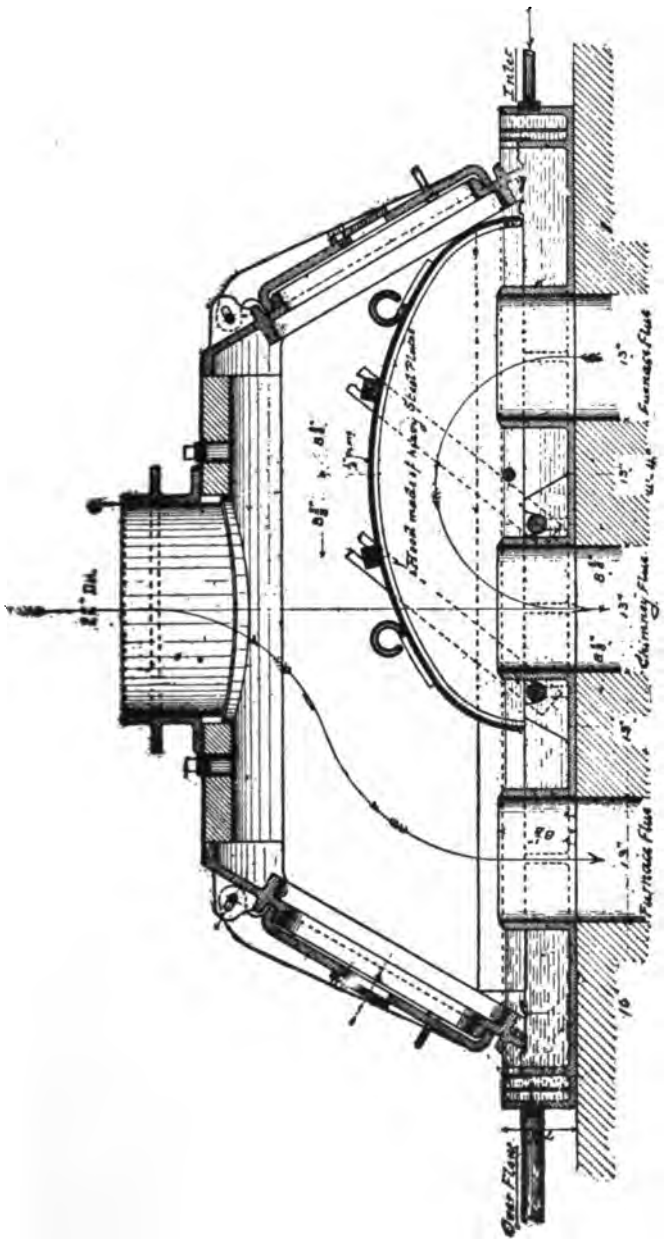


FIG. VIII-I.—FORTER VALVE.

eye, deep-blue glasses being used as a protection from the intense glare. I have elsewhere* shown that the practiced eye can detect a difference of 13° C. in the temperature of Bessemer charges, and this may also be taken as the skill to which many open-hearth melters attain. The intense heat of a regenerative furnace is made possible by the preheating of the gas and air in chambers which have been warmed by the products of combustion, these chambers being alternately heated by currents traveling from the furnace to the valves, and cooled by currents going from the valves to the furnace. If the currents were not reversed, the chambers on the outgoing end would be heated uniformly throughout their length to about the temperature of the furnace, while, at the same time, the chambers on the incoming end would be cooled to the temperature of the incoming gases. By the reversal of the currents there is a continual conflict between these extremes, so that the ends next the melting chamber are at a bright yellow heat, and the ends next the valves are about 200° F. (say 100° C.) above the temperature of the incoming gases.

Air always enters cold, but it is believed by some furnacemen that it is economical to have the gas as hot as possible. To some extent this is an error, for the checkers in the outer end of the gas chamber cannot be cooled below the temperature of the entering gas, and the products of combustion cannot be cooled below the temperature of these checkers, so that the heat carried in by hotter fuel is carried out by hotter waste gases, and no economy is obtained. With hot gas, however, it is not necessary to pass such a large proportion of the products of combustion through the gas chambers, and an extra amount may be diverted to the air chambers, where the heat may be used to advantage. This gain may be important when the coal contains only a small proportion of the denser hydrocarbons, for under these conditions the gas leaves the producer at a high temperature; but when the coal is very rich the gas is at a low temperature when it comes from the fire, and the gain from its immediate use may be inappreciable. It is true that all the tar is utilized when hot gas is used, but this represents only a small part of the total calorific development.

SEC. VIIIi.—*Calorific equation of an open-hearth furnace.*—

* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 392. See also certain remarks in Sec. VII.

Several years ago I published an investigation into the calorific balance of an open-hearth furnace.* Quite recently other experiments have been conducted by von Jüptner,† and as our results did not agree, I have made a new determination. There are at Steelton two acid-lined 50-ton furnaces, running on a coal consumption of 500 pounds per ton of steel. Deducting for idle time leaves 440 pounds (200 kg.) for heating and melting. The heat from internal combustion is shown by the following comparison of the data given by von Jüptner and the old experiment at Steelton:

Element oxidized.	Per cent. of total charge.	
	Jüptner.	Steelton.
Si	0.48	0.41
Mn	1.23	0.88
C	1.03	0.95
Fe	2.24	0.98

According to Jüptner the value of this combustion was 169,560 calories per ton of steel, while at Steelton it was 143,000 calories, the difference being due to the greater loss of iron in the first case. In the new experiment it will be assumed that internal combustion produces 155,000 calories per ton.

The total energy of coal and stock is dissipated in many ways:

(1) Lost in unburned carbon in producer ash.
(2) Absorbed in internal reactions in the producer.
(3) Lost as sensible heat in producer gases.
(4) Absorbed by the metal in heating and melting.
(5) Lost as sensible heat in waste gases from furnace.
(6) Lost in excess air from furnace.
(7) Lost in unburned hydrogen and carbonic oxide.
(8) Lost by radiation and conduction.

Some of these losses are without compensation, such as the carbon in the ash and the radiation; some are useful, such as the absorption by internal reactions; some are utilizations, like the absorption of heat in melting. In order to find the proportion of energy utilized

* *The Physical and Chemical Equations of the Open-Hearth Process. Trans. A. I. M. E.* Vol. XIX.

† *Chemisch-Calorische Untersuchungen uber Generatoren und Martinofen von Hanns v. Jüptner und Friederich Toldt.*

it is necessary to know the amount theoretically required. According to von Jüptner the heating and melting of the stock calls for 328,250 calories per ton; in the former experiment I had called it 290,000 calories. Taking an average of the two gives about 310,000 calories, which will be the figure used in the new work. Tables VIII-A, B and C show the detailed calculation, the methods being as follows:

The carbon of the fuel minus the carbon in the ash gives the total carbon in the gas. Total carbon in the gas divided by the carbon in one cubic meter gives the volume of gas produced. Carbon in one cubic meter is found from the principle that one cubic meter of either CO, CO_2, or CH_4 contains 0.54 kg. of carbon; C_2H_4 contains twice that weight. The calorific value of the gas is found by multiplying the volume of each combustible ingredient by the calorific power of one cubic meter of the combustible gas, and adding the products. The products of the dry distillation of the coal are taken from results on a similar coal at the beginning of distillation, coked in Semet-Solvay coke ovens, as reported by Prof. H. O. Hofman. The volume of CH_4 and C_2H_4 in the gases may be assumed as coming all from this distillation; the volume of H gas distilled off is a little less than the CH_4. The volume of CO and CO_2 in the total gases, minus that coming from the distillation, gives the CO and CO_2 formed by combustion in the producer. The total volume of free hydrogen produced, minus that coming from the distillation, gives the free hydrogen liberated in the producer by the decomposition of steam. The total weight of hydrogen in the gas in every form (CH_4, C_2H_4, H and H_2O) minus the weight of hydrogen in the coal in any form (assumed as 4 per cent. in the dried coal and 0.5 per cent. present as hygroscopic water) gives the hydrogen which must have come in with the blast. Assuming average humidity of the air, the weight of hydrogen present in it as moisture is calculated; the difference between this and the total hydrogen of the blast is the hydrogen coming in from the steam jet, whence the weight of steam blown in.

The heat created in the producer is from formation of CO and CO_2. Some of this is rendered latent by being absorbed in the decomposition of H_2O in the blast. This heat reappears in the open hearth when the gases are burnt; it is part of their calorific power. The rest of the heat created in the producer is lost as sensible heat

in the hot gases or by radiation and conduction. These losses are definite losses. The total calorific power of the coal is the calorific power of the gases produced, plus the definite losses of heat from the producer, as just defined. The proportion these losses bear to the total calorific power of the coal is the percentage of producer loss.

Von Jüptner used no steam jet, and therefore had little decomposition of steam in his producer. He, however, calculates the total calorific value of the coal by adding together the calorific power of the gases and the total heat created in the producer, including, moreover, in the latter item the heat of combustion of the hydrogen of the coal which goes into the gases as water. Aside from the fact that he uses the calorific power of hydrogen to liquid water, wrongly including the irrecoverable heat of vaporization of steam, the above calculation of the total calorific power of the coal contains two erroneous items, viz.: (1) any heat rendered latent in the producer by decomposition of steam is counted twice, once in the heat developed in the producer, and the second time in the calorific power of the gas. This item is small in this particular case, but is considerable in the Steelton producers. (2) Including the heat of formation of the water in the gas coming from the combination of hydrogen of the coal with oxygen in the coal is practically assuming that all the H of the coal is free to burn, and neglects the principle of "available hydrogen" or "hydrogen free to burn." The calorific power of the coal is thus increased by this quantity more than the power of the coal can really be, and the surplus thus found above the experimentally ascertained calorific power of the coal is called by von Jüptner the "heat of gasification" (Vergasungswärme) of the coal. This is entirely a hypothetical quantity which has no place in the calculations in theory and no existence in practice.

Von Jüptner is also in error in using 0° C. as a basis, for this is an arbitrary point having no relation to the problem. It would be as logical to use —10,000° C., but if we did so the heat brought into the furnace by gas and air and stock would be in excess of the heat produced by combustion—an answer quite correct theoretically, but absurd practically. The proper datum is the average temperature of the stock, gas and air entering the valves.

The working of the producer is shown in Table VIII-C. Von

Jüptner loses 25.9 per cent. in producer ash against 2.1 per cent. at Steelton. Of the 74.1 per cent. actually utilized, von Jüptner gets 50.7 per cent. potential in the gas, or only 68 per cent. of the potential of the coal consumed. But of the 97.8 per cent. utilized at Steelton 78.4 per cent. is potential in the gas, or 80 per cent. of the potential of the coal. The Steelton practice is, therefore, 26.7 per cent. better in burning the coal and 10 per cent. better in utilizing the combustion for the making of gas. The former advantage is due to better construction and operation; the latter to the steam jet, which transfers 10 per cent. of the energy in the coal from the producer to the furnace.

The following conclusions may be drawn from the tables:

(1) A producer demands one-quarter to one-fifth of all the heat value of the coal, delivering the remainder as potential in the gas.

(2) If the loss of coal in the ash is very high, the gas may contain less than half the value of the coal.

(3) The heat produced by the combustion of the silicon, carbon and iron of the bath is one-seventh as much as is supplied by the combustion of the gas.

(4) The heat from the combustion of the metalloids and of the iron is one-half the quantity necessary to heat and melt the charge.

(5) The distribution of heat in the open-hearth furnace must be calculated in percentages of the sum of the heat supplied by the gas plus the heat supplied by internal combustion.

(6) About one-half of all the heat supplied to an open-hearth furnace is lost by radiation and conduction.

(7) About one-quarter of the heat is lost in the waste gases going to the chimney.

(8) About one-quarter of the heat is utilized in heating and melting the stock.

These conclusions are founded on experiments where the coal consumption throughout the month was 500 pounds per gross ton of steel ingots. Where the coal consumption is higher, the percentage of heat utilized will be less, and the amount lost by radiation and in waste gases will be greater. The total loss in waste gases at Steelton was 23.4 per cent. of the total value of the coal, and the gases escaped to the stack at an average temperature of 680°, this average being based on an estimate of the proportional amount escaping from the two chambers, the temperature of each

having been determined. The average temperature of the gas and air was 280° C., so that there was a loss of 23 per cent. for 400° C., or 6 per cent. for each 100° C., so that an increase in the cubical content of the regenerative chambers, sufficient to reduce the temperature of the waste gases 100° C., will effect a saving of 6 per cent., and after allowing for the gain in heat from the metalloids and the loss of heat in the producer, this will be a saving of from 25 to 45 pounds of coal per ton, depending on the fuel economy of the furnace. The loss from radiation and conduction is twice the loss in the escaping gases, but this item includes all the experimental errors.

HEAT OF COMBUSTION OF FUELS.

	Per molecular weight.	Per kilo.	Per c. m.
C to CO	29,400	2,450	
C to CO_2	97,600	8,133	
CO to CO_2	68,200	2,436	3,069
H to vapor H_2O	58,080	29,040	2,614
CH_4 to CO_2 and H_2O gas	191,560	11,970	8,620
C_2H_4 to CO_2 and H_2O gas	319,260	11,400	14,367
Si to SiO_2	180,000	6,430	
Fe to FeO	65,700	1,173	
Fe to Fe_2O_3	195,600	1,746	

Physical constants used in the calculations:

Weight of 1 c. m. H gas (at 0° and 760 m. m.) 0.09 kg.
Weight of 1 c. m. any other gas=0.09 kg.x1/2 its molecular weight.
Weight of C in 1 c. m. of CO, CO_2,CH_4=0.54 kg.
Mean specific heat of 1 c. m. from 0° to t° C.

CO, H, N or O	0.306+0.000027 t
CO_2	0.374+0.00027 t
H_2O	0.342+0.00015 t
CH_4	0.418+0.00024 t
C_2H_4	0.424+0.00052 t

TABLE VIII-A.

Distribution of Heat in the Producer.

Coal per ton of steel produced, pounds	440
Coal per ton of steel produced, kilogrammes	200
Carbon in coal, per cent	75.68
Carbon in 200 kg. coal, kg	151.36
Ash in coal, per cent	7.12
Carbon in producer ash, per cent. of ash	21.07
Carbon in producer ash, per cent. of coal	1.90
Heat value of carbon in ash per 200 kg. coal, calories	30,700
Producer gas: composition by volume, per cent. (dry gas) CO_2, 5.7; CO, 22.0; CH_4, 2.6; C_2H_4, 0.6; H, 10.5; O, 0.4; N, 58.2.	

Steam accompanying 1 c. m. gas (determined) c. m.....	0.0375
Calorific value per cubic metre, calories.....	1260
Carbon in one cubic metre dry gas, kg.....	0.1689
Carbon in gas per kg. of coal (0.7568—0.0190) kg.....	0.7374
Volume of gas per kg. of coal (0.7378÷0.1689) c. m. (dry)	4.37
Volume of dry gas per 200 kg. coal, c. m.....	874
Calorific value of gas per 200 kg. of coal, calories.....	1,101,240

Products of dry distillation of 1 kg. coal (assumed).

CO_2 0.026 kg.=0.013 c. m.
CO 0.027 kg.=0.022 c. m.
CH_4 0.082 kg.=0.114 c. m.
C_2H_4 0.033 kg.=0.026 c. m.
H 0.0098 kg.=0.109 c. m.

Volume of CO_2 in gas per kg. of coal (0.057×4.37) c. m...	0.249
Volume of CO_2 from distillation of 1 kg. coal, c. m.....	0.013
Volume of CO_2 produced by combustion, per kg. coal, c. m.	0.236
Volume of CO_2 produced by combustion per 200 kg. coal, c. m.	47.2
Heat of formation of 47.2 c. m. CO_2 calories.....	207,300
Volume of CO in gas per kg. of coal (0.22×4.37) c. m.....	0.961
Volume of CO from distillation of 1 kg. coal, c. m.....	0.022
Volume of CO produced by combustion, per kg. coal, c. m.	0.939
Volume of CO produced by combustion per 200 kg. coal, c. m.	187.8
Heat of formation of 187.8 c. m. CO, calories.....	248,460
Total heat created in producer per 200 kg. coal, calories..	455,760
Temperature of gas leaving the producer, degrees Cent...	655
Mean specific heat of dry gas (20° to 655°) (calculated)..	0.3468
Sensible heat in dry gases per 200 kg. coal (874×.3468×635)=	192,470
Mean specific heat of steam (20° to 655°).....	0.443
Sensible heat in steam per 200 kg. coal (0.0375×874×0.443 ×635)	=9280
Total sensible heat in gas and steam per 200 kg. coal calories	201,750
Volume of free H in gas per kg. of coal (0.105×4.37) c. m.	0.459
Volume of free H from distillation of 1 kg. coal, c. m.....	0.109
Volume of free H from decomposition of H_2O in producer, c. m.	0.35
Volume of free H from decomposition of H_2O per 200 kg. coal, c. m.....	70
Weight of H liberated from H_2O per 200 kg. coal, kg.....	6.3
Heat thus absorbed in decomposing steam, calories.....	182,700
Total weight H in 1 c. m. gas, including steam, kg.....	0.0186
Weight H in gas per 200 kg. coal, kg. (0.0186×874).....	16
Weight H in 200 kg. coal (200×0.045), kg.....	9
Weight H coming from air and steam, per 200 kg. coal, kg.	7
Weight H_2O coming from air and steam, per 200 kg. coal, kg.	63
Weight H_2O coming from air used, at average conditions, kg.	9.6
Weight steam blown in, per 200 kg. coal, kg.....	53.4
Weight of steam decomposed in producer (6.3×9), kg...	56.7
Deduct moisture of air, assumed all decomposed, kg.....	9.6
Steam of steam jet decomposed, per 200 kg. coal, kg.....	47.1
Percentage of steam in steam jet decomposed $\left(\frac{47.1}{53.4}\right)$	88

Heat generated in producer, calories	455,760
Heat taken out of producer in gas and steam	201,750
Surplus left in producer, calories	254,010
Absorbed in decomposing steam (rendered latent)	182,700
Loss by radiation and conduction, calories	71,310

Summary of above results on Producer Practice, per 200 kg. coal.

	Calories.
Lost as carbon in ash	30,700
Lost by radiation and conduction	71,310
Sensible heat of hot gas and steam	201,750
Total heat loss of producer	303,760
Calorific power of producer gas	1,101,240
Total heat value of coal	1,405,000
Per cent. lost in producer	21.6

Losses in the Producer in Percentage of the Heat Value of the Coal.

	Calories.	Per cent. of value of coal.		Per cent. of total producer loss.	
Lost as C in ash	30,700	2.1		10.1	
Radiation and conduction	71,310	5.1		23.5	
Sensible heat of steam	9,280	0.7	14.4	3.1	66.4
Sensible heat of dry gas	192,470	13.7		63.3	
	303,760	21.6		100.0	

TABLE VIII-B.

Distribution of Heat in the Furnace.

C in gas per kg. of coal, kg	0.7378
C in gas per 200 kg. coal, kg	147.56
C in 1 c. m. (dry) chimney gas, kg. (0.127×0.54)	0.06858
Volume (dry) chimney gas per 200 kg. coal, c. m	2152
Free oxygen present in this gas (2152×0.067), c. m	144
Excess air corresponding to free oxygen, c. m	699
CO_2 in chimney gas (2152×0.127), c. m	273
N in chimney gas (2152×0.806), c. m	1735
N in excess air used, c. m	536
N in theoretical products of combustion, c. m	1199
N in producer gas per 200 kg. coal (874×0.582), c. m	509
N in air necessary for theoretical combustion, c. m	690
Air necessary for theoretical combustion, c. m	872
Excess of air used, percentage 680÷872	78
H_2O in chimney gas (2152×0.078), c. m	168
Heat in air used, at 280°, Sm (0° to 280°)=0.314—	
Theoretical air needed (872×0.314×280), calories	76,650
Excess air used (680×0.314×280), calories	59,770
Total, calories	136,420

Heat in producer gases used, at 655°—	
Dry gas 874 c. m. (874×0.347×655), calories	92,650
Steam 33 c. m. (33×0.440×655)	9,510
Total, calories	102,160
Total heat brought to furnace, not available, calories	238,580
Heat taken out in chimney gases, at 680°—	
Dry, theoretical combustion (1472×0.367×680), calories	367,750
Steam formed (168×0.444×680), calories	50,190
Total in theoretical products of combustion, calories	417,940
In excess air used (680×0.324×680), calories	149,820
Total in the chimney gases, calories	567,760
Heat brought to furnace and not available, calories	238,580
Heat loss in chimney chargeable against furnace, calories	329,180
Proportion of chimney loss chargeable against furnace, per cent.	58

Items of Chimney Loss Chargeable Against Furnace:

	Calories.	Per cent.
Dry gases from theoretical combustion	213,220	64.8
Steam from theoretical combustion	29,100	8.8
Excess air used	86,860	26.4
	329,180	100.0

Summary of Above Results on Furnace Practice per 200 kg. Coal =One Ton Steel.

	Calories.
Potential value of gas	1,101,240
Combustion of metalloids	155,000
Total heat available	1,256,240

Sensible Heat in Waste Gases Chargeable Against the Furnace.

	Calories.	Per cent. of available energy.
(a) Dry, theoretical products of combustion	213,220	17.0
(b) Steam of theoretical products of combustion.	29,100	2.3
Total in the theoretical products of combustion	242,320	19.3
(c) Excess air used	86,860	6.9
Total in entire products of combustion	329,180	26.2
Heating and melting stock	310,000	24.7
Radiation and conduction (by difference)	617,060	49.1
Total, as above	1,256,240	100.0

TABLE VIII-C.

Distribution of Heat in Producer and Furnace Combined.

Per Ton of Steel.	Von Jüptner.				Campbell.			
	Original.		Corrected (Richards).		Old Determination.		New Determination (Richards).	
	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.	Amount (calories).	Per cent. of total.
Coal in producer, pounds	.....	.....	854	.....	638	.....	440	.....
Heat value of coal, kilogramme calories	.....	.....	2,337,450	.....	2,377,420	.....	1,405,000	.....
Producer practice—								
Lost as carbon in ash	.....	.....	606,470	25.9	140,650	5.6	30,700	2.1
Heat generated in producer which is lost, i. e., not used in furnace	.....	.....	547,730	23.4	694,840	27.6	278,060	19.5
Potential of gas used in furnace	.....	.....	1,183,250	50.7	1,541,930	66.8	1,101,240	78.4
Total—value of coal as above	.....	.....	2,337,450	100.0	2,377,420	100.0	1,405,000	100.0
Furnace practice—								
Potential in gas as above	1,252,080	.....	1,183,250	83.2	1,541,930	.....	1,101,240	87.6
Combustion of metalloids	169,560	.....	169,560	11.9	143,000	.....	155,000	12.4
In gas, air and stock	225,430	.....	69,930	4.9				
Total available heat for furnace	1,647,070	.....	1,422,740	100.0	1,684,930	.....	1,256,240	100.0
Sensible heat of dry gases of theoretical combustion (chargeable)	392,500	23.8	258,580	18.0	210,580	12.5	213,220	17.0
Sensible heat of steam of theoretical combustion (chargeable)	169,170	10.3	38,060	2.7	24,670	1.5	29,100	2.3
Sensible heat of excess air (chargeable)	124,320	7.6	116,830	7.7	10,790	0.6	86,860	6.9
Unburnt combustible in waste gases	.....	.....	.....	.....	58,590	3.5	.....	.....
Total in waste gases chargeable against the furnace	685,990	41.7	413,440	28.4	304,580	18.1	329,180	26.2
Absorbed in heating and melting	328,250	19.9	328,250	23.1	290,000	17.2	310,000	24.7
Radiation and conduction (by difference)	632,880	38.4	681,150	48.5	1,090,350	64.7	617,060	49.1
Total in furnace as above	1,647,070	100.0	1,422,840	100.0	1,684,930	100.0	1,256,240	100.0
Percentage of the total heating power of the coal and metalloids utilized in heating and melting stock	.....	.....	.....	13.5	.....	11.5	.....	20.0

CHAPTER IX.

FUEL.

SECTION IXa.—*The combustion of fuel.*—A full definition of the word "fuel" would involve the calorific value of silicon, manganese, phosphorus and iron, but, as usually understood, the term embraces only the forms of carbon known as charcoal and anthracite coal, and combinations of carbon and hydrogen, such as natural gas, petroleum and bituminous coal, while the meaning of "combustion" is narrowed down to the union of such substances with oxygen. For practical purposes it may be considered that in all compounds of hydrogen and carbon there is an isolation of each element just previous to union with oxygen, so that the molecular history may be represented by the following equations:

$$C+2O=CO_2,$$

1 kilo C+2 2/3 kilos O=3 2/3 kilos CO_2,
producing 8133 calories.

$$CO+O=CO_2,$$

1 kilo CO+4/7 kilo O=1 4/7 kilos CO_2,
producing 2438 calories.

1 cubic meter CO+1/2 cubic meter O=1 cubic meter CO_2,
producing 3072 calories.

$$2\ H+O=H_2O,$$

1 kilo H+8 kilos O=9 kilos H_2O,
producing 34,500 calories, including latent heat in steam.
29,040 calories, not including latent heat in steam.

1 cubic meter H+1/2 cubic meter O=1 cubic meter H_2O,
producing 2614 calories, not including latent heat in steam.

$$C+O=CO,$$

1 kilo C+1 1/3 kilos O=2 1/3 kilos CO,
producing 2450 calories.

The above equations represent the combustion of carbon and hydrogen with oxygen. This never occurs in practice, for they are burned with air, which is a mixture of oxygen and nitrogen, the proportion by weight being 23.2 oxygen and 76.8 nitrogen, and by volume 20.9 oxygen and 79.1 nitrogen; so that the products of combustion from burning coal are composed in great part of nitrogen. The products from hard coal and soft coal vary somewhat, because soft coal contains about 5 per cent. of hydrogen, the

TABLE IX-A.

Products of Combustion of Hard and Soft Coal.

Excess Air.	Hard Coal.		Soft Coal.	
	CO_2 Per Cent.	O Per Cent.	CO_2 Per Cent.	O Per Cent.
No excess.	21.0	0.0	19.1	0.0
10	19.1	1.9	17.3	2.0
20	17.5	3.5	15.8	3.6
30	16.1	4.8	14.5	4.9
40	15.0	6.0	13.5	6.1
50	14.0	6.9	12.6	7.1
60	13.0	7.8	11.7	8.0
70	12.3	8.6	11.0	8.8
80	11.7	9.3	10.4	9.5
90	11.1	9.9	9.9	10.1
100	10.5	10.5	9.4	10.6

oxidization of which produces water, and ordinarily in taking a sample of the gases this water is condensed, and does not appear in the analysis. In order to burn this hydrogen it is necessary to supply a certain quantity of air which carries nitrogen, so that the products from soft coal contain a slightly higher percentage of nitrogen and a slightly lower percentage of carbonic acid than will be obtained from hard coal.

Table IX-A shows the composition of the products of combustion of hard and soft coal when burned with varying amounts of air. The first line gives the results when just sufficient air is added to completely burn the carbon and hydrogen and each succeeding line shows an additional 20 per cent. of air. An excess is necessary to insure complete combustion, the amount of excess varying with the conditions under which the coal is burned, but it is seldom possible to have complete combustion with less than 30 per cent. excess air.

Combustion of carbon (coal) with no excess of air:

1 kg. carbon+8.87 cu. metres air=1.86 cu. m. CO_2+7.01 cu. m. N.

Combustion with 100 per cent. excess:

1 kg. carbon +17.74 cu. m. air=1.86 cu. m. CO_2+14.02 cu. m. N +1.87 cu. m. O.

The equations given herewith represent the volume of air required by each kg. of carbon and the volume of the products caused by the combustion under two different conditions. Excess air means a considerable loss of heat, but there will be a loss in the waste gases even if there be no excess of air, for the products of combustion carry off a great deal of sensible heat. The amount so carried will depend upon the temperature of the waste products, as shown in Table IX-B. If the gases from a coal-fired boiler

TABLE IX-B.

Loss of Heat in Products of Combustion of Hard Coal.

	Temperature of gases; degrees Cent.				
	100° C. 210° F.	200° C. 390° F.	300° C. 570° F.	400° C. 750° F.	600° C. 1110° F.
Specific heat of waste gases—					
No excess air	.328	.336	.344	.352	.367
20 per cent. excess	.327	.334	.341	.348	.363
40	.324	.331	.338	.345	.358
60	.322	.328	.335	.341	.354
80	.320	.326	.332	.338	.349
100	.318	.324	.329	.334	.345
Per cent. of heat lost—					
No excess air	3.8	7.5	11.3	15.5	24.0
20 per cent. excess	4.5	8.9	13.4	18.4	28.3
40	5.1	10.3	15.4	21.1	32.5
60	5.8	11.7	17.5	23.9	36.8
80	6.5	13.0	19.5	26.7	41.0
100	7.2	14.4	21.6	29.5	45.3

escape at 200° C., 390° F., a temperature which is attainable, the loss in sensible heat is 7.5 per cent. when no excess air is present, but if 100 per cent. of excess air is used the loss will be 14.4 per cent. When the temperature is 300° C., 570° F., the loss with 100 per cent. excess air is 21.6 per cent. and with 400° C., 750° F., it is 29.5 per cent.

SEC. IXb.—*Producers.*—In almost all metallurgical operations where gas is used for heating, the fuel in the producer is bituminous

coal; but in special cases anthracite coal is used. Soft coal is converted into gas by burning it in a thick fire. Air is blown in beneath the grate, and a jet of steam is also admitted to keep down

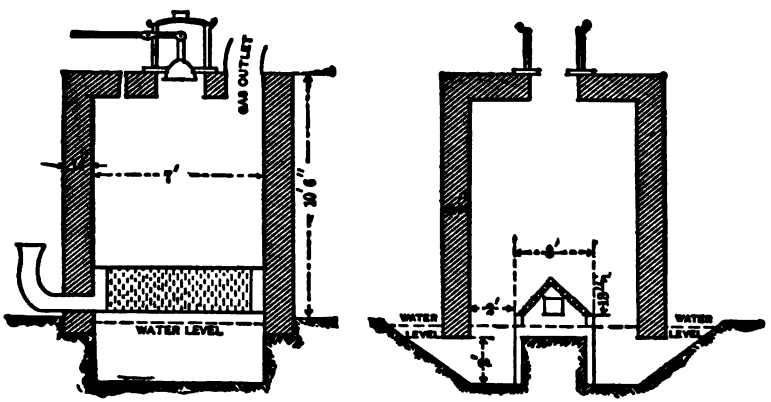


FIG. IX-A.—WATER SEAL PRODUCER.

the temperature. Within the last few years the water seal producer has been generally adopted. Many different forms have been used, but the main principles of the construction are illustrated in Fig. IX-A. The space below the water level is full of ashes, which can be removed without interfering with the operation of the producer. The ashes will fill the room for one or two feet above the water line. Above this will be glowing carbon, and the air as it goes up forms carbonic acid (CO_2), and this rising through the bed of coal absorbs more carbon and becomes carbonic oxide (CO), but this action is never complete, and some carbonic acid passes through the fire unchanged. With a hot deep fire free from cavities the gas may contain as low as 2.5 per cent. by volume of CO_2, but if the fire be thin or riddled with holes there may be as much as 10 per cent.

In the "zone of combustion" the steam is broken up by the carbon with formation of hydrogen and carbonic oxide, but, as in the reduction of carbonic acid, this reaction is never perfect and some steam goes through unaltered. The best decomposition is attained in a hot fire, but this is just the condition that is not desirable on account of the formation of clinkers. On the other hand, if the supply of steam be increased indefinitely the fire will get colder

and colder, producing no gas and letting steam and air pass through unconsumed. There is a mean between these extremes which is almost forced upon the operator, wherein the fire is kept at a constant temperature, and in this condition there is not much increase in hydrogen from the steam, while a little steam passes away with the gases.

In the upper zone of the fire, the volatile hydrocarbons of the fuel are distilled by the heat beneath, and in this way the gaseous products contain a certain proportion of tarry vapors, part of which is condensed in the conducting tubes. The zones of combustion and distillation are not separated by any arbitrary line, but some of the rich components of the coal are carried down into the body of the fire and exposed to a high temperature. This causes the separation of carbon, some of which is burned with the coal, while the rest is carried forward into the conducting tube. When the fire is hot, large volumes of soot are formed in this way and give trouble in the pipes, but when cool there is little soot, but much tar. The worst condition is when holes form in the bed of coal. This allows air to come through and burn the hydrocarbons above the fire with a smoky soot-producing flame, cakes the coal into an unworkable mass, and increases the percentage of carbonic acid in the gas.

In Sec. VIIIi were discussed certain producer experiments, and the gas there given may be taken as representative of ordinary practice, the composition being as follows:

Siemens Gas.	Per cent. by volume.
CO_2	5.7
C_2H_4	0.6
O	0.4
CO	22.0
H	10.5
CH_4	2.6
N, by difference	58.2
	100.0

Some of these percentages, notably of CO_2, H, and CH_4, vary through wide ranges according to the condition of the fire, but the nitrogen will always be about 60 per cent. This component remains passive throughout all the future history of combustion, but it so reduces the calorific intensity that the gas is applicable only to regenerative furnaces.

The ordinary methods of gas analysis fail to take definite account

of any save true gaseous components, but in the products of a soft-coal fire there are certain amounts of soot and tar. Some of these are deposited in the conduits, but they do not constitute a great part of the total energy. In the case of an exposed 7-foot iron pipe, 250 feet long, the condensation of tar amounted to only three-tenths of 1 per cent. of the total heat value,* while the gas itself, after passing through the tube, contained a proportion that represented from one-tenth to one-eighth of the total heating power. In spite of the low calorific power of this tar it is found that, when the suspended matters are removed by scrubbing, the value of the gas is reduced very seriously, for the tar gives luminosity to the flame and thereby renders it able to heat not only by direct impact, but by the no less potent action of radiation. It is by virtue of this quality that the luminous flames from the dense hydrocarbons surpass the clear products of an anthracite fire.

The investigation given in Sec. VIIIi showed that the losses of energy in a producer as operated at Steelton were as follows:

Lost as carbon in ash	2.1
Sensible heat of dry gas	13.7
Sensible heat of steam in gas	0.7
Radiation and conduction (by difference)	5.1
Total	21.6

The total shows that over one-fifth of all the heat value of the coal is lost. The figure for radiation and conduction is determined by difference, and hence bears all the errors in the determinations. The other items offer ground for discussion.

(1) The carbon in the ash.

In Sec. VIIIi reference was made to experiments by von Jüptner in which the loss of carbon in the producer ash represented 20 per cent. of the total value of the coal, for the ash from the producer contained 74 per cent. of carbon and only 26 per cent. of true ash. Such a waste is entirely unnecessary, for it is possible to run soft-coal gas producers where the ash contains less than 20 per cent. of carbon, and averages from 12 to 18 per cent. It is possible to estimate very closely how much is lost if we know the percentage of carbon in the ash and the percentage of ash in the original coal. The latter point must be taken into consideration, for if the coal

* *The Open-Hearth Process.* *Trans. A. I. M. E.*, Vol. XXII., p. 376.

contains 13 per cent. of ash, and if the waste from the producer contains 87 per cent. of carbon, it would show that no work had been done in the producer and that there was 100 per cent. waste,

TABLE IX-C.

Value Represented by Carbon in the Ash.

	Per Cent. of Total Heat Value Lost.			
Per Cent. Ash in Coal.	4	7	10	13
20 per cent. C in ashes.....	1.5	2.5	3.2	4.0
40 " " "	3.0	5.5	7.0	8.5
50 " " "	4.0	7.0	10.0	13.0
60 " " "	5.5	10.0	14.5	20.0
70 " " "	8.0	15.0	21.0	.....
80 " " "	15.0	25.0	.....	.....
85 " " "	20.0	.....	.....	.....

but if the coal contained only 4 per cent. ash and the ashes contained 87 per cent. carbon, it would show that only 30 per cent. of the coal had been wasted. The heat value represented by certain percentages of carbon in the ashes are given in Table IX-C. With a coal of 7 per cent. ash and with producer ash containing less than 20 per cent. of carbon, the loss of heat value is less than $2\frac{1}{2}$ per cent. of the value of the coal, which is a radical difference from the loss mentioned by von Jüptner, wherein 20 per cent. of the total was thrown away.

(2) Sensible heat in gas and steam.

The sensible heat of producer gas is wholly wasted, for in a regenerative furnace the gain in heat on the incoming end is balanced by the loss in hotter outgoing gases. In the experiment by von Jüptner, the average temperature of the producer gas in four experiments is 267° C. I am inclined to doubt these temperatures, for von Jüptner's loss from radiation and conduction alone was as much as all the factors in the Steelton practice combined, while the loss from sensible heat was low, on account of the low temperature of the escaping gases. The loss by radiation was determined by difference, and a cold fire should not give as much loss by radiation as a hot one, so that possibly von Jüptner took the temperature of the gases at some distance from the producer and the item of radiation included part of the sensible heat of the gas. Under this

assumption the radiation from the producer becomes more nearly what would be expected, although a detailed comparison is useless owing to the confusing way in which von Jüptner calculates the hydrogen on the basis of its full calorific value, including the latent heat of condensation. This has already been referred to at length in Chapter VIII.

It is possible that the fires were at a low temperature for a short time, but they could hardly be run continuously under such conditions. I have operated a fire for several hours at a black heat, but at the end of that time the whole top of the fire had become a bed of tar, so that it was impossible to do any poking, and it was necessary to stop charging fresh coal, decrease the amount of steam and allow the fire to burn up and break up the tarry matters.

It may appear at first sight that the presence of carbonic acid (CO_2) in the gas is the most important loss, but this item is taken care of under the head of sensible heat and under radiation; an excess of carbonic acid must give rise to heat and this heat must show itself somewhere. If it is used to dissociate steam then it is not lost, for the gas will be enriched by the hydrogen, consequently it is not entirely right to assume that a slight increase in carbonic acid means poorer practice. The gas above quoted as made at Steelton ran as follows:

$$CO_2=5.7 \qquad H=10.5$$

If less steam had been used the fire would have been hotter, and if properly poked would have shown a lower percentage of CO_2; but it would also have shown a lower percentage of H, so that nothing would have been gained in the calorific value of the gas, and the heat value of the coal would not have been better conserved.

TABLE IX-D.

Value Represented by CO_2 in Gas.

2	per	cent.	CO_2=	5.3	per	cent.	loss
3	"	"	"	8.0	"	"	"
4	"	"	"	10.8	"	"	"
5	"	"	"	13.7	"	"	"
6	"	"	"	16.6	"	"	"
7	"	"	"	19.6	"	"	"
8	"	"	"	23.0	"	"	"
9	"	"	"	26.5	"	"	"
10	"	"	"	30.0	"	"	"

Notwithstanding that a higher content of carbonic acid is not conclusive proof of bad practice under usual conditions the percentage of carbonic acid is an index of the fuel economy. Table IX-D shows the percentage of the heat value of the coal represented by certain proportions of CO_2 in the gas, provided that the heat produced by its formation is not utilized in the decomposition of steam. In ordinary producer practice the carbonic acid runs from 4 to 6 per cent., indicating a loss of 11 to 16 per cent. of the heat value of the coal, but under exceptionally good practice the gas will carry between 3 and 4 per cent. of carbonic acid, indicating a loss of 8 to 11 per cent., thus causing a saving of 5 per cent. in the amount of coal. With bad practice the gas may contain 10 per cent. of carbonic acid, indicating a loss of 30 per cent. of the heat value, or about 17 per cent. more than is necessary, the amount of coal consumed being one-sixth more than would be used in good practice. A high percentage of carbonic acid may be detected without the aid of a chemist, for it is bound to show itself in a hot fire, and the sensible heat of the gases is not only the result, but the measure of the waste.

Hard coal is about equal to soft coal when used for firing boilers, and the smaller sizes are extensively used for this purpose. They are also used in producers, but it is necessary to inject steam at the grate or the producer becomes unmanageably hot. The steam rots the clinkers and cools the fire, and hydrogen is produced as in the manufacture of water gas. The gas is of about the following composition:

	Per cent. by volume.
CO	27.0
H	12.0
$CH_4+C_2H_4$	1.2
CO_2	2.5
N	57.3

This anthracite gas is nearly equal in producing low temperatures, such as firing boilers or drying ladles, but is far inferior in creating an intense heat, even when regenerated; probably this inferiority lies in the absence of the suspended volatilized tarry matters, which are characteristic of soft-coal gas. These components have an appreciable heating value, but their main function is to give luminosity to the flame, and to increase its power of radiation.

SEC. IXc.—*Miscellaneous fuels.*—There are some fuels which are essentially local in their character like natural gas and oil, but which are extensively used in metallurgical operations.

(a) *Natural gas:*

In the favored district lying just west of the Alleghenies in Pennsylvania, West Virginia, Ohio and Indiana, natural gas has been used for all kinds of heating from about 1884 until the present time. The composition varies in different wells, but in all cases the gas is made up of members of the paraffine series, with not over one-half of 1 per cent. of carbonic acid (CO_2) and from 2 to 12 per cent. of nitrogen. By ultimate analysis it gives 70 per cent. of carbon and 23 per cent. of hydrogen, while, by ordinary methods, it shows from 67 to 93 per cent. of marsh gas, the remainder being principally hydrogen. At first this gas was passed through regenerative chambers, but this was discontinued owing to the deposition of soot and to the discovery that sufficient heat was obtained by leading the gas directly to the ports and burning it with air which had been regenerated in the usual manner. Of late years the supply of gas has been decreasing and the demand has been met by the constant drilling of new wells in new territory. There is a limit to this method, and it would seem that before many years this fuel will cease to be a factor in the larger operations of a steel works.

(b) *Petroleum:*

Crude oil may be transformed into a vapor by atomizing with steam and superheating the mixture, but unless exposed for some time to a yellow heat it remains a vapor, and hence will condense if carried through long, uncovered pipes or introduced into the cold valves of a regenerative furnace. It may be put into the chambers at some point where the temperature is high, and in this way condensation will be prevented as well as the waste heat be utilized. There is a partial molecular rearrangement with the steam, but the action is far from perfect, for, after passing through 20 feet of small brick flues at a yellow heat, the product may contain 20 per cent. of free aqueous vapor. The mixture of oil vapor and steam may be burned in a muffle, for, after the walls are red hot, there is a reciprocal sustentation of heat; but the use in reverberatory furnaces is wasteful, since the action is sluggish. Even in regenerative practice a charge of cold stock retards combustion much more with oil than with coal gas, and even at maximum temperatures the

flame is longer on account of there being double work to do before the combustion is complete. Each molecule of oil, as it comes into a hot furnace, undergoes a process of dissociation, the rich hydrocarbons breaking up under the tension of internal molecular activity. This absorbs heat, and for an instant the disruption lowers the temperature below the point of ignition. Moreover, as each point of oil explodes, it makes a small balloon of gas, and it takes a moment for this to become mixed with the air necessary for its combustion. If steam is present its reduction by carbon entails a certain delay.

These matters may seem trifling, but they are probably the explanation of the very important fact that, under the usual conditions of furnace operation, a flame from oil vapor is longer than a flame from coal gas. In the burning of clear carbonic oxide, or a mixture of it with nitrogen, there is no preliminary decomposition to be performed, the air being free to immediately touch and burn the molecules of the fuel.

It is impossible to state the comparative economy in the use of coal and oil, since their relative values vary so widely in different localities, but it may be assumed that 50 gallons of oil are equivalent to 1000 pounds of soft coal in regenerative furnaces or under boilers.

(c) *Water gas:*

NOTE: This discussion is condensed from an article by George Lunge, in *The Mineral Industry* for 1901.

When steam is passed over incandescent carbon the subjoined reaction takes place:

$$C+H_2O=CO+H_2.$$

Equal volumes of carbon monoxide and hydrogen are formed, the mixture possessing the caloric value of 2800 metric heat units per cu. m., an amount one-half the heat value of gas made by distilling bituminous coal in retorts. The heat produced by gram-molecules is for $CO+H_2+O_2=CO_2+H_2O=68.4+57.6=126$ heat units, whereas the direct combustion of carbon, $C+O_2=CO_2$, produces only 97 heat units. The introduction of water cannot be the source of energy, and the apparent gain of 126—97=29 heat units must come from the heat that accumulates in the incandescent fuel.

The reaction: $C+H_2O=CO+H_2$ is endothermic; i. e., it takes place with expenditure of heat. The splitting up of H_2O requires 57.6 heat units, of which only 28.6 are supplied by the reaction $C+O=CO$, so that 29 heat units has to be made good. These 29 heat units must be supplied apart from the incandescent fuel, the temperature of which soon falls below the point where the reaction $C+H_2O=CO+H_2$ is prevailing (assumed to be above 1000° C.). Below this temperature another reaction comes into play, viz., $C+2H_2O=CO_2+2H_2$, which produces a gas composed of one-third inert carbon dioxide and two-thirds combustible hydrogen. This second reaction is also of endothermic character, and if real water gas is to be made, the operation is divided into two distinct phases or stages. Beginning with incandescent coal in a generator 2 or 3 m. in height, at a temperature of about 1200° C., steam, preferably in the superheated state, is introduced and water gas is formed according to the reaction,

$$C+H_2O=CO+H_2.$$

Soon, however, the temperature sinks and carbon dioxide CO_2 is produced by the secondary reaction,

$$C+2H_2O=CO_2+2H_2.$$

Before the carbon dioxide begins to prevail, the steam must be shut off, the temperature being then below 1000° C. This whole period of steaming lasts four or five minutes, and the gas contains by volume 48 to 50% H, 40 to 45% CO, 4 to 5% CO_2 and 4 or 5% N, and has a value of about 2600 heat units per cu. m. After the steam is shut off, the blowing up begins; air is blown into the generator. When the temperature reaches the required degree the air is shut off and the generator is ready for another steaming. Until recently the blowing up was carried on as in the making of ordinary producer gas, but in the Dellwik-Fleischer process* such conditions are established in the generator that complete combustion to carbon dioxide is obtained. The difference in results are outlined herewith:

* *Journal I. and S. I.*, May, 1900.

	Per 1 pound carbon.	
	Old way.	Dellwik.
Water gas, cubic feet	21.7	44.7
Heat units	3627	7465
Per cent. utilized	48.0	92.5

SEC. IXd.—*Heating furnaces.*

(a) *Soaking pits.*—In the steel plants of Europe no coal is used to heat the ingots in the blooming-mill, but in a Gjers soaking pit they heat themselves from internal heat.

(b) *Regenerative furnaces.*—Regenerative furnaces are generally used for heating ingots or blooms when these ingots or blooms are red hot to start with. Ingot furnaces in America resemble a Gjers soaking pit and are operated in much the same manner, small quantities of gas and air being admitted. The coal used need not exceed 40 pounds per ton, and half this amount is sufficient.

(c) *Reverberatory furnaces.*—A reverberatory furnace is one in which the fire is at one end, the stack at the other, and the stock is placed on the hearth between, the flame passing over the top of whatever is placed upon the hearth. Such furnaces are quite generally used for heating cold blooms or billets, but their operation is far from perfect, for when a full heat of cold stock is charged, the absorption of heat is so great that combustion is retarded and a clear hot flame cannot be obtained. At a later period of the operation, when the blooms are hot, a clear flame cannot be carried, as the metal would be oxidized. During the advanced stages, it is necessary to run a smoky flame, and as the blooms are of nearly the same temperature as the flame, very little heat is utilized in the furnace, but most of the energy passes out the flue. After the blooms have reached their proper state and while they are being drawn all the heat entering the furnace goes out the stack. In ordinary reverberatory furnaces the amount of fuel used to heat a ton of steel is twenty times as much as theory would call for. One way of getting more perfect combustion is to introduce air at the bridge wall, but this often results in loss, as the flame will be sharp and the metal be oxidized. A loss of only 1 or 2 per cent. of steel will more than balance any saving in fuel.

Where coal is cheap the flame from the heating furnace is often

allowed to escape directly into the stack, but it is much more economical to let it pass through a boiler. The amount of heat available varies with the condition of the charge, being less after the furnace is filled with cold blooms and greatest when they are at the full heat. The boiler need not be big enough to absorb all the waste heat during the short period when the furnace is hottest, but should be more than big enough to handle the minimum. Steam must be made, and if not made by this waste heat then it must be supplied from the fire-room. Following is a general statement of the heat balance:

(1) For each ton of coal used in twelve hours in the firebox, the waste heat from the furnace averages from 25 to 30 horsepower.

(2) A furnace at its highest heat represents a development of 35 horse-power per ton of coal burned in twelve hours.

(3) When a furnace is supplied with a boiler capable of absorbing one-half of all the heat created at the highest temperature of the furnace, the average loss throughout the day will be one-third of the total made, or one-half of what is utilized, this being due to the fact that this limited capacity is enough at certain periods, and that the boiler makes beyond its rated and economical capacity, as shown by the great loss of heat in the escaping gases.

(4) When a furnace is equipped with ample boiler capacity, the horse-power developed by each ton of coal put into the firebox will be one-half as much as would be developed by the same coal if burned under an ordinary stationary boiler.

In Table IX-E are given analyses of the waste gases from soft-coal reverberatory furnaces after passing through boilers. In the first column is given the interval from the time when the furnace was charged to the time when the test was taken, and in the second column is given the number of tests that were averaged to give the composition stated. Observations were made as to the time when fresh coal was added, but the analyses did not seem to show any relation thereto. Thus there were 14 tests showing over 6 per cent. CO, and the average time since coaling for these was 13 minutes. There were 20 tests showing less than 3 per cent. CO, and the average time since coaling was 16 minutes. There were 8 tests with over 6 per cent. oxygen, and the average time since coaling was 16 minutes.

TABLE IX-E.

Waste Gases from Reverberatory Furnaces.

Interval from charging furnace to taking tests.	No. of Tests.	CO_2	CO	O
Less than 20 minutes.....	17	10.8	4.9	4.2
20 minutes to 1 hour.....	18	11.9	3.9	2.9
1 hour to 2 hours.....	6	11.8	7.5	0.5
2 hours to 3 hours.....	7	10.6	7.2	1.1
3 hours to 4 hours..	6	9.8	4.2	5.4
True average.....	54	11.0	5.0	3.0

The results are so nearly uniform that we may take the average to find the loss of heating power due to the escape of unburned CO and also the loss of heat by the excess of air or oxygen. The results are given in Table IX-F, the loss from excess of oxygen being calculated on the assumption that the gases leave the boiler at a temperature of 250° C.=480° F. As already explained, the operation cannot be conducted for the benefit of the boiler, for the proper heating of the steel is the first consideration, but there is room for improvement when over one-fifth of all the power is wasted by non-combustion.

TABLE IX-F.

Calculations on Waste Gases from Reverberatory Furnaces.

	Kind of Gas		
	Average	2 h. 30 m.	3 h. 30 m.
Composition { CO_2 per cent....	11.0	10.6	9.8
CO per cent....	3.0	7.2	4.2
O per cent....	5.0	1.1	5.4
Loss from CO per cent....	21.5	27.8	20.8
Loss from O per cent....	3.6	0.5	3.3
Total loss per cent.....	25.1	28.3	24.1

(d) *Continuous furnaces.*—A continuous furnace is a reverberatory furnace, where the blooms or billets are fed in at the flue end, pushed toward the firebox and drawn when they reach the hottest part. The pieces are hot when they reach the vicinity of the fire, and, therefore, the combustion of the fuel is facilitated, as the flame coming over the bridge wall is never cooled by freshly charged blooms, as in the intermittent fur-

nace. As the flame goes onward to the flue end, it finds colder and colder blooms and gives up its heat, so that if we conceive a furnace of indefinite length, the escaping gases will be entirely cold.

One of the difficulties about a continuous furnace is to move the pieces from one end to the other. The natural and almost universal way is to put the hearth on an angle, but some power must be applied. In Europe, where such furnaces are common, it is not unusual to roll the blooms or ingots forward by hand labor, but the cost of such labor would be prohibitive in America, while this practice gives rise to heavy loss, as the coating of scale falls off at every turn and exposes a fresh surface to oxidation. It is impossible to say how much of the heavy oxidation in some foreign works is due to this cause and how much to a sharper flame than is customary in America. Rails are sometimes buried in the hearth of the furnace, which are replaced when they burn away, the ingots being pushed forward by power; in other cases, no rails are used, but the ingots are simply pushed along the sand bottom, which is much torn by the operation.

In America the general practice is to have the billets rest on water-cooled pipes. These pipes absorb considerable heat and cool the under side of the bloom somewhat, but the gain in time and labor covers this small loss. Such furnaces in this country, with few exceptions, are used for billets not over 6 inches square, since it is difficult to heat larger blooms uniformly on the top and bottom, and there is not time when they reach the end of the furnace to turn them over and let the under side get hot. In the exceptions just noted, the blooms are of uniform size and the conditions are favorable, a furnace of this type being successfully operated on pieces 8 inches square and 10 feet long. The continuous furnace saves little fuel, for it does not produce steam like a reverberatory furnace, but it saves considerable in furnace labor.

SEC. IXe.—*Coke ovens.*—Almost all the coke of America and about three-fourths of that produced in England is made in bee-hive ovens, whereby a pile of coal is burned slowly until the volatile matters are expelled, these volatile matters passing away in clouds of smoke. This smoke is a rich gas during the early stages of the operation, and might be used as a source of heat if such plants were in the neighborhood of industrial establishments. In Belgium and Germany bee-hive ovens were long since superseded by

retort ovens, by which is meant any construction wherein the coal is heated in a closed muffle by the combustion of the gases distilled from itself. The gases so distilled may be taken from the tops of the retorts and carried to purifiers, where the tar and ammonia are extracted, in which case they are called by-product ovens.

In other cases the gas is taken directly from the upper part of the coal chamber to the combustion passages underneath. By this method the by-products cannot be obtained, but the gases reach the flues at a red heat, while in by-product work they are thoroughly cold. Consequently, when no by-product work is attempted, less gas is needed to perform the coking and more heat is available for steam raising. It is also possible to use a leaner coal, containing less volatile matter. Thus we might say that if the gas be scrubbed free from tar and thoroughly cooled, the coal should contain 18 per cent. of volatile matter, in order that sufficient calorific value be brought to the flues, while a coal with 15 per cent. of volatile matter would furnish sufficient gas, if this gas were brought red hot into the flues with all the tar in suspension. These figures are not to be accepted literally, as much depends on the nature of the volatile matter. Some Semet-Solvay ovens in Belgium are working on coal with only 17 per cent. of volatile matter, with profitable recovery of the by-products. In this country some Pocahontas coal has been worked with 18 per cent. of volatile constituents.

In Germany a considerable proportion of the ovens have no by-product plant attached and some of these are new installations, while at many other works the chemical industry is very profitable. In general, it may be said that the retort oven without by-products is best where the value of these products is small, and where the retort system yields a large increased percentage of coke in comparison with the bee-hive, or where superior density is of advantage.

The gas expelled from the coal during the first stages of the operation will be rich and in great volume, but there follows a time when it decreases, but it is necessary to continue the distillation to have the coke dense. During this latter period the coal is not self-supporting, in that the gas burned in the flues is more than the gas produced, and the freshly charged ovens near by must make up the deficit. It is possible to keep separate the product made during the

early part of the process and use this in supplying cities with illuminating gas, reserving the later product, containing less illuminants, for burning in the flues.

The following remarks are quoted from Blauvelt:* "There are two distinct types of retort-ovens, viz., the vertical and horizontal flue types. In the former there are thirty-odd vertical flues in each wall between the ovens. These are connected at the top and bottom by larger horizontal flues, running the length of the oven, the lower one being divided into two parts by a partition midway between the ends. The gas is burned in the lower flue, the flame rising through half the vertical flues and descending through the other half, and escaping usually to regenerators of the ordinary reversing type, which heat the air for the combustion. The course of the gases is reversed about every hour and sent through the flues in the opposite direction.

"In the horizontal flue oven the gas is burned in horizontal flues, usually three in number, which are connected at the ends to form a continuous system, the gas being admitted through small pipes at the ends of the top and middle flues, where it meets air for the combustion. The gases travel from above downward, pass under the bottom of the oven, through a recuperative arrangement for heating the air, and then to boilers, where steam is made for operating the plant."

Fig. IX-B is an example of the Semet-Solvay horizontal flue type at Ensley, Ala., while Fig. IX-C shows the regenerative Otto Hoffman ovens at the works of the Maryland Steel Company at Sparrow's Point, Md.

Of the total number of coke ovens in the United States in 1903 as given in the Census Report, only about two per cent. were of retort construction, while in Germany there were not 2 per cent. of bee-hives. This difference is due to several causes. One is that the bee-hive oven makes a superior coke from Connellsville coal, and there is a prejudice or belief that the retort coke will not be as good. Another reason is that the cost of the ovens is very much greater.

The advantages of retorts appear in using a coal poor in volatile matter, for when such coal is coked in bee-hives, a great deal of the fixed carbon must be burned to supply heat, and the yield of coke

* *Trans. A. I. M. E.*, 1898.

is small; with the closed oven the heat required is less, a smaller amount of combustible suffices and the only loss in weight is the volatile part. Thus, with a rich coal, the yield of coke is the

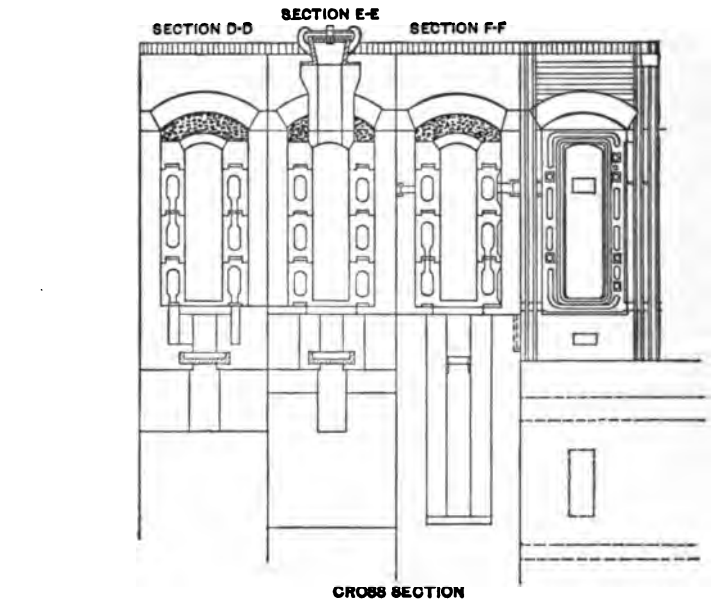


FIG. IX-B.—SEMET-SOLVAY COKE OVEN.

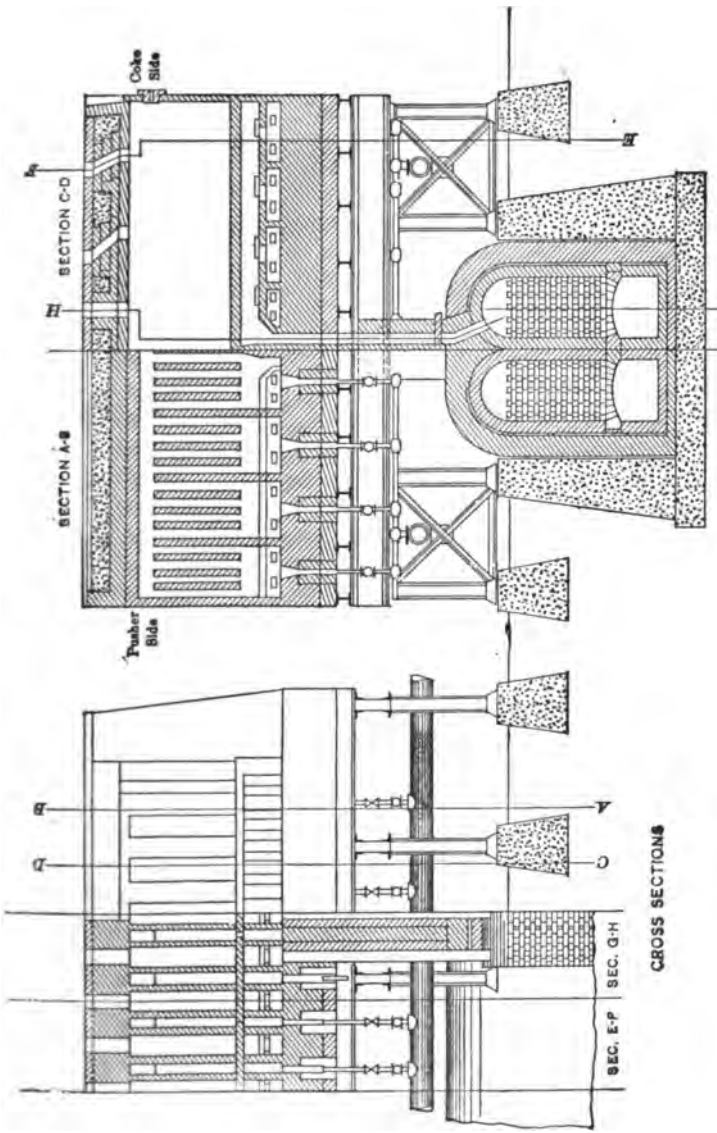


FIG. IX-C.—OTTO HOFFMAN COKE OVEN.

same in the bee-hive and the retort, the latter, however, giving an excess of gas for other uses; while with poor coals the yield of coke is greater in the retort oven. It is not correct to say that the yield of coke can be accurately estimated from the laboratory tests on fixed carbon, for there is a complicated reaction in the retort oven and in the bee-hive, whereby the dense hydrocarbons are broken up after they are distilled and deposit carbon in the mass of coal, so that it is possible to produce more coke than there was fixed carbon in the coal. The proportion so made depends upon the molecular arrangement of each particular coal.

England has been slow in building retort ovens. They have been used for many years on the lean coals of South Wales, but it is only recently that they have come into general use in the Cleveland district and around Leeds. Rapid progress has been made within a few years. The total coke production of England is supposed to be from twelve to thirteen million tons, and the retort ovens now erected in the Kingdom have about one-quarter of that capacity.

SEC. IXf.—*Coal washing.*—Many deposits of coal contain a high percentage of ash or sulphur, or both. Proper washing will reduce both, but the extent of the purification will depend on the way in which they are combined. If most of the sulphur is in coarse grains of pyrite, it can be easily removed by a bumping-table or a one-spigot washer, but if a large proportion is fine, then some combination of sieves and jigs must be installed. If, unfortunately, the sulphur exists as sulphate of alumina or lime, or as organic matter, it may be impracticable, even by a jigging plant, to bring it down to the point required for good coke. The washing of coal is a separation of minerals founded on their unlike rate of falling in water, but, under favorable conditions, the results obtained by very simple apparatus may suffice for commercial work. In many other cases more complicated processes are necessary, while in all cases the better apparatus will give a purer product. In one complete plant in Western Germany the coal in its natural state carries from 22 to 30 per cent. of ash, which is reduced to about 10 per cent. At an English works a coal of 30 per cent. is brought down to 6 per cent. In Alabama 17.69 per cent. ash is cleaned down to 6.7 per cent., and 1.6 per cent. sulphur to 0.74 per cent.

CHAPTER X.

THE ACID OPEN-HEARTH PROCESS.

SECTION Xa.—*Nature of the charge in a steel-melting furnace.* —In acid open-hearth practice the shell is first lined with nine inches or more of clay brick. The furnace is then heated to the working temperature, and sand is spread in successive layers over the entire hearth. Each layer is heated to a full heat for about ten minutes or until it is "set," so as to be hard, the sand being selected so that it will give a dense and solid bottom. When finished, the thickness of the lining should be from 18 to 24 inches. The area of the cavity for holding the charge will be determined by the size of the furnace, for the depth of the metal should be about 12 to 15 inches in a 5-ton furnace and from 18 to 24 inches when the charge is 30 to 50 tons. If the bath is shallow, the oxidation is excessive; while if deep, the melting is slow.

The constituents of the charge vary in different places. Sometimes pig-iron alone is used, but when scrap can be obtained it forms part of the mixture. It is necessary, however, to have a certain amount of pig-iron to protect the iron from oxidation. The stock must be low in sulphur and phosphorus, as there is no elimination of these elements.

The content of silicon, manganese and carbon is not limited by narrow bounds, for these elements are oxidized during the process and their presence in greater or lesser amounts alters the working of the charge rather than the composition of the product. In the manufacture of soft steel it is the usual practice, when scrap is available, to regulate the proportion of pig-iron so that the bath, after melting, shall be free from silicon and manganese, and shall contain from three-fourths to one per cent. of carbon. During the elimination of this element, the metal is in continual ebullition, and its temperature and condition, as well as the character of the slag, may be controlled in preparation for recarburizing and cast-

ing. If too small an amount of pig-iron is used, the molten bath will contain neither silicon, manganese, nor carbon, and will be viscous and pasty. Such a mass will be oxidized by the flame, and the oxide of iron will scorify the bottom.

SEC. Xb.—*Chemical history during melting.*—The amount of oxidation during melting is increased by the presence of hydrogen in the gas, by a sharp flame, and by a port construction that allows free air to impinge upon the metal. It is also determined by the manner in which the stock is charged. The pig-iron should be spread evenly over the scrap, so that it will melt first and trickle over the hot steel, and thus each atom of iron will be protected by an atom of silicon or carbon for which oxygen has a greater affinity.

It is impossible to obtain perfect protection, and when only a small proportion of pig is used there will be spots where the scrap is entirely uncovered, and large amounts of iron oxide will be produced. If this cinder forms a pool on the viscous surface of the charge, it will be mixed sooner or later with high-carbon metal, and an interchange will occur with reduction of iron, the result being the same as if mixture had taken place at an earlier stage; but if the fused oxide comes in contact with the hearth, scorification will ensue with formation of silicate of iron, and though at a later period this scoria may be mixed with high-carbon metal, the harm cannot be completely remedied. A portion of the iron may be reduced and a higher silicate formed, but silica once having entered the slag is there to stay, and will permanently hold a greater or less amount of iron oxide.

The value of the elements found in pig-iron in protecting the scrap from oxidation will be in proportion to their ability to unite with oxygen, as shown by the following table:

1 unit of carbon combines with 1.333 units of oxygen to form CO.
1 unit of silicon combines with 1.143 units of oxygen to form SiO_2.
1 unit of manganese combines with 0.291 unit of oxygen to form MnO.
1 unit of titanium combines with 0.176 unit of oxygen to form TiO_2.

This table represents a broad truth, but some elements are preferable to others. It is necessary that, after melting, the metal should be protected from the flame by a layer of slag containing about 50 per cent. of silica. If the charge is made up of one-quarter pig-iron carrying 1 per cent. silicon, the silica produced by oxidation, the sand attached to the pig-iron, and the material

from the scouring of the hearth are usually sufficient for the requirements of the cinder, but with low-silicon pig-iron, free from adhering sand, it may be necessary to add additional silica to prevent the basic slag from making inroads upon the bottom. On the contrary, if the silicon in the pig-iron is high, the slag will be

TABLE X-A.

Elimination of Metalloids in an Open-Hearth Charge.

Nature of Sample.		Group I.	Group II.
Pig-iron pounds		11,700	20,700
Steel Scrap, pounds		45,550	36,900
Composition of original charge, per cent. (estimated)	Si	0.40	0.65
	Mn	0.90	0.85
	C	1.00	1.50
Metal when melted, per cent.	Si	.02	.05
	Mn	.09	.06
	C	.54	.64
Slag after melting, per cent.	SiO_2	50.24	49.46
	MnO	21.67	18.16
	FeO	23.91	28.27

viscous and infusible. Manganese helps to counteract this viscosity, but in the absence of this element iron oxide must be added in the shape of ore, or formed from the bath by waste of iron.

The way in which the metalloids are eliminated during the melting will be understood from Table X-A. Each column represents the average of consecutive charges; Group I includes nineteen heats melted with soft-coal producer gas, and Group II six heats made with oil vapor. The oil vapor is more oxidizing than the coal gas, so that although the original charge was higher in oxygen-absorbing elements, the bath, after melting, had the same composition in both cases. The slag shows a great variation in the oxides of iron and manganese, for the amount of manganese was limited by the content in the charge, and since the slag required a certain proportion of bases, the deficit was made up by oxidation of iron.

SEC. Xc.—*Chemical history after melting.*—After the melting it is necessary to oxidize the remaining carbon, manganese, and silicon, by keeping the bath at a high heat and adding iron ore in successive doses, thus forming silica and oxide of manganese which go into the slag, and carbonic oxide which escapes with the flame. This combustion of carbon produces a bubbling over the entire surface of the bath, exposing the metal to the flame, and keeping it at

a high temperature. The union of the oxygen of the ore with the silicon and carbon sets free metallic iron, which is immediately dissolved by the bath.

If the ore is added properly, it is reduced as fast as it is put in, as will be evident from Table X-B, which shows the history of the metal and the slag in the groups above considered. In Group I an average of 1020 pounds of ore was used on each heat to decarburize, while on Group II only 850 pounds was added, but in spite of the addition of the ore the character of the slag remains unchanged. There is an increase of FeO, but this does not show an increase in basicity, for the volume of slag is increasing, both from the wear of the hearth and the silica from the ore, so that in order that the composition of the slag should remain the same it would be necessary that there be a simultaneous supply of exactly the right proportions of both MnO and FeO. This cannot happen, for the metal after melting is nearly free from manganese, and since the ore contains none there is no source of supply of this element. With the dilution of the slag, there is a vacancy left for a base, and iron oxide is the only available candidate. That this is the true explanation will be seen from the totals of MnO and FeO, which show that the slag at the end of the operation is almost identical with the slag after melting, since the sum of these factors represents the real basicity of the cinder.

TABLE X-B.

History of Metal and Slag in an Acid Furnace.

Subject.		Composition, per cent.			
		Group I. 19 heats soft coal gas.		Group II. 6 heats oil gas.	
		After melting	End of operation.	After melting.	End of operation.
Metal.	Si	.02	.02	.05	.01
	Mn	.09	.01	.06	.02
	C	.54	.13	.64	.12
Slag.	SiO_2	50.24	49.40	49.46	49.36
	MnO	21.67	16.50	13.16	11.30
	FeO	23.91	29.79	33 27	34 11
	MnO+FeO	45.58	46.29	46.43	45.41

SEC. Xd.—*Quantitative calculations on acid slags.*—The foregoing results do not show the alteration in the amount of the slag during the operation. It is out of the question to weigh the cinder at different periods, but it is possible to approach the truth by the following method: The final slag, after tapping, is weighed. By subtracting from this weight the MnO produced by the addition of the recarburizer and the sand from the tap-hole and ladle-linings, the amount of slag which was in the furnace before tapping may be computed. Given the analysis of the slag at that time, it is easy to calculate the weight of its constituents, among which will be the manganese; if the ore contained none of this element, the amount which was present throughout the operation will be known; and since the percentage of manganese in the slag and in the metal can be determined, and the weight of the metal can be calculated for any stage of the work, all the data are at hand for a determination of the weight of the slag at any time.

This process applied to the two groups of heats in Table X-B gives the results in Table X-C, where it is shown that although nearly twice as much pig-iron was added in Group II, as in Table X-A, the greater oxidizing power of the oil flame took care of this extra amount, the result being seen in the greater quantity of slag after melting. When the bath was thoroughly fluid, the oil flame still acted more powerfully, but was unable to burn the iron, since the metalloids furnished ample protection, and the increase in the weight of slag during oreing is no greater in one group than in the other. In Group I, 41 per cent. of the ore was reduced, while

TABLE X-C.

Reduction of Ore.

Subject.	Group I. Coal gas, pounds.	Group II. Oil gas, pounds.
Slag after tapping	4050	5670
Slag after melting	2810	4580
Ore added	1020	850
FeO in ore added	648	586
FeO reduced during oreing	386	312

in Group II there was 45 per cent. These figures have no general significance, for, if the slag is viscous after melting, a certain amount of ore will be necessary to confer fluidity and will not be

reduced. Since this quantity will be a constant under given conditions, no matter how much ore is afterward needed, it might be 90 per cent. of a small addition and only 10 per cent. of a large one.

SEC. Xe.—*Reduction of iron ore.*—This reduction of ore is a matter of importance in using large proportions of pig-iron. Quite an amount of oxide is then necessary to satisfy the silicon of the pig, as well as the sand adhering to it, but after the slag is formed there is no increase in its volume, except from the impurities in the ore and the wear of the hearth, so that as fast as the ore is added its oxygen is transferred to the metalloids, and its iron to the bath.

TABLE X-D.

Slag and Metal at Different Periods of the Operation.

COMPOSITION OF THE SLAG.

Pounds of ore added.	Constituents, after addition of ore as shown in first column.	Number of Heat.				
		7596	7598	7606	7685	Average
None.	SiO_2, per cent.	50.27	51.96	52.48	52.94	51.90
500	" "	49.27	51.10	55.82	51.72	51.98
1000	" "	52.77	50.80	55.73	52.28	52.77
1500	" "	50.97	51.48	55.06	52.90	52.75
None.	MnO, per cent.	14.91	21.65	15.61	21.84	18.50
500	" "	15.20	19.09	15.81	20.44	17.51
1000	" "	14.70	17.50	13.89	19.06	16.39
1500	" "	14.22	16.72	12.40	16.36	14.92
None.	FeO, per cent.	31.28	22.59	27.14	23.18	26.05
500	" "	30.68	26.12	25.11	24.21	26.53
1000	" "	26.96	28.26	26.20	26.26	26.92
1500	" "	31.70	26.08	26.96	29.13	28.45
None.	FeO and MnO, per cent.	46.14	44.24	42.75	45.02	44.54
500	" "	45.88	45.21	40.42	44.65	44.04
1000	" "	41.66	45.76	40.09	45.33	43.21
1500	" "	45.92	42.75	39.86	45.49	43.26

COMPOSITION OF THE METAL.

Heat No.	Silicon, per cent.				Manganese, per cent.			
	After adding ore, as below.				After adding ore, as below.			
	None.	500 lbs.	1000 lbs.	1500 lbs.	None.	500 lbs.	1000 lbs.	1500 lbs.
7596	.07	.01	.01	.01	.10	.02	.02	.02
7598	.04	undet.	undet.	.01	.02	.02	.02	.02
7606	.04	.05	.08	.02	.08	.05	.03	trace.
7685	.18	.07	.05	.06	.19	.08	.09	.10

This may be illustrated by Table X-D, which gives the records of heats, on each of which 1500 pounds of ore were added after melting to decarburize the metal.

SEC. Xf.—*Pig-and-ore process.*—The amount of ore required for

a charge will not follow closely the amount of carbon, since the flame is constantly at work, and ore is added when the melter thinks it advisable rather than when absolutely necessary. If the charge is hot, it dissolves the ore rapidly and there is little chance for the flame to do its share of oxidation, while if the charge is cold only a small amount of ore will be added and the oxygen will be derived from the gases. It may be broadly said that if the bath contains 1 per cent. of carbon, 1500 pounds of ore may be used in bringing it down to .05 per cent. The first 500 pounds will reduce it to about .80 per cent. of carbon, the second to .40 per cent. and the third will finish the work. If silicon and manganese should be as low during the interval between the first and second ore additions as at a later time, the burning of the carbon might be the same then as later, but either the presence of these protectors or the less favorable physical condition of the slag in a high-carbon bath retards the action at the start. When large quantities of high-silicon or high-manganese pig-iron are used, the first additions of ore are consumed by the unburned excess of these elements, and hundreds and even thousands of pounds of ore may be added after melting before the carbon is affected. Therefore, when it is necessary to charge nothing but pig-iron, it is advisable to have it contain as little silicon as possible, and even then the oxidation of carbon requires several hours. The ore is not lost, for the reduced iron makes up for the metalloids which are burned, so that the weight of the steel may equal or exceed the weight of the pig-iron charged.

The expense of the pig-and-ore process rests in the slow combustion of carbon, for it is impossible to hurry the work without causing violent boiling of the voluminous slag, producing scorification of the hearth and possibly a loss of metal through the doors. The process upon an acid hearth is much slower than on a basic bottom, for in the latter case a slag rich in iron does not have disastrous results upon the hearth. Since the fuel consumption per hour is nearly the same during the period of oreing as it is during the period of melting, there is a considerable decrease in product with an increased fuel ratio.

SEC. Xg.—*Conditions modifying the product.*—If the temperature of the metal is high, the last traces of silicon will not be oxidized. In the Bessemer converter the metal may contain as much

as 1 per cent. of silicon if blown sufficiently hot, but in the open hearth there is no chance for the bath to arrive at an intense degree of heat as long as a considerable percentage of this element is present; for superheating is not readily attained without a lively bath, and the bath will very seldom be lively as long as it holds a high content of silicon. Thus the open hearth cannot rival the converter in producing high-silicon metal by non-combustion, but under suitable conditions the amount carried along in the metal may be quite appreciable, and, by holding the bath at a very high temperature with a silicious slag, there will even be a reduction of the silica of the hearth. This variation in affinity plays an important part in the production of steel castings.

The presence of silicon, due to high temperature, tends to prevent the absorption of gases, and it is stated by Odelstjerna* that if at any time the metal is allowed to cool, so that the last traces of silicon are burned, the gases which are absorbed cannot be expelled by a subsequent superheating.

Odelstjerna is doubtless correct in his statements, but there may be other factors involved in a full explanation. It is certain that in the manufacture of small ingots to be rolled directly into plates, there are delicate adjustments of temperature and slag that are not easily explained by considering silicon alone. One of these factors is the extent and force of the oxidizing influence. It is the opinion of some metallurgists that the best quality of open-hearth steel can only be made when the burning of the metalloids is carried on at a slow rate, so that the bath shall not contain an excess of oxygen at any time, and it is stated by Ehrenwerth† that a certain American works makes a practice of keeping a charge in the furnace a very long time when a good quality of steel is desired. As a matter of fact, the works in question did carry out such a system at one time out of respect to foreign tradition, but found no advantage in so doing, and has discontinued the practice.

It is also an opinion, held by men of reputation, that a high proportion of pig-iron in the original charge will give a superior product. If this is true, it probably arises from the fact that the presence of a high proportion of carbon after melting, with the

* *Trans. A. I. M. E.*, Vol. XXIV, p. 308.

† *Das Berg- und Hüttenwesen auf der Weltausstellung in Chicago.* Ehrenwerth, 1895, p. 276.

consequent long exposure to the flame, will result in a thorough washing of the bath. I believe that there is a limit to this action, and that little can be gained by raising the content of carbon in the melted bath above 1 per cent., for this proportion insures a vigorous boil. It is difficult to see how the condition of the bath, after it has been run down from 1 per cent. of carbon to three-tenths of 1 per cent., can be different from the condition which would have existed if the original content had been 2 per cent. It seems probable that one or two hours of exposure of the completely liquid bath to the flame would give ample opportunity for any reactions which could be in progress.

SEC. Xh.—*Sulphur and phosphorus.*—In the above records no account is taken of sulphur or phosphorus, but experience proves that the content of phosphorus in the steel will be determined by the initial content in the charge. It is true that acid open-hearth slag may contain some phosphorus, and I have found one case where it held 0.04 per cent., but it would require a higher percentage than this to make a difference in the metal that could be detected by ordinary analysis, so that it must be assumed that every molecule of phosphorus in the pig-iron, scrap and ore will appear in the finished metal.

The percentage of sulphur cannot be predicted with precision. Traces of this element may be burned during melting and pass away as sulphurous anhydride, but the proportion eliminated is small. On the other hand, there is a tendency to absorb sulphur from the flame, and with bad coal, and especially when the slow working of the furnace renders it necessary to expose the charge to the gases for a long time, the amount thus absorbed may be ruinous. It has been suggested that the addition of lime in the producer might retain at least a part of the sulphur in the ashes of the producer, but it would give trouble by making a fusible ash. The ore is also a source of contamination, for it generally contains pyrites. As the ore floats on the bath some sulphur may be oxidized above the surface and the products pass away with the flame, but the remainder will be absorbed by the bath.

SEC. Xi.—*Tests.*—The condition and nature of the metal and slag are determined by taking samples from the furnace by means of a small ladle and casting test-ingots with a cross-section about one inch square. These are chilled in water and broken, and the

carbon is estimated from the appearance of the fracture. The reliability of such a determination depends upon the constancy of the conditions of casting and chilling, and the expertness of the judge, but, roughly speaking, the content can be ascertained within 10 per cent. of the true amount.

SEC. Xj.—*Recarburization.*—When the desired point has been reached the recarburizer is added, being almost invariably used in a solid state. It is generally heated red hot, but this is not essential, for, in making structural steel, "ferro" containing 80 per cent. of manganese is used almost exclusively, and the weight of the addition is so small that it chills the bath only slightly. The ferro may be added to the metal while in the furnace, and this method has the advantage that the bath can be thoroughly stirred after the recarburizer has melted, but it has the disadvantage that during the time the last pieces are fusing, the portions which melted first are losing their manganese to the oxygen of the slag and flame. In a hot furnace this action is very rapid, and although the entire addition may melt in less than a minute, a considerable proportion of manganese is lost by oxidation. When the recarburizer is added in the ladle, the latter action will not occur, but there will be a certain loss from the oxide of iron contained in the metal, and the function of the recarburizer is to remove this oxygen. The loss of manganese will be the same whether the addition is made in the furnace or in the ladle, but in the latter case the effects of slag and flame are absent. Hence, it follows that the loss will be more regular when recarburization is performed in the ladle, and the content of manganese in the steel more nearly alike throughout a series of heats.

The manganese lost in recarburization not only varies with the way in which it is added, but also with the percentage of carbon and manganese in the bath. The amount of oxide in the bath is less with high than with low carbons, and so the loss of manganese decreases as higher steel is made. Moreover, the loss is less with smaller percentages of manganese, so that if 1.00 per cent. of Mn be added there will be .60 per cent. in the metal, being a loss of .40 per cent., while if .50 per cent. be added the steel will have .40 per cent., being a loss of only .20 per cent. It seems as if with the lower manganese the action was not perfect, and that with each successive increment of ferro an additional atom of oxygen is re-

moved. This fact holds good whether the recarburizer is added in the furnace or in the ladle.

The fear of non-homogeneity under the practice of adding the ferro in the ladle is not entirely unfounded when small heats are made and the metal is not hot, but when charges of 20 to 50 tons of hot steel are properly poured and recarburized, the steel is uniform. When metal is made high in manganese, certain precautions must be taken; but in ordinary structural steels, when the manganese runs below .65 per cent., there is an all-pervading action throughout the melted mass which dispels all thought of non-homogeneity.

CHAPTER XI.

THE BASIC OPEN-HEARTH PROCESS.

SECTION XIa.—*Construction of a basic open-hearth bottom.*—The basic open-hearth process consists in treating either melted or solid pig-iron, or a mixture of pig-iron and low-carbon metal, upon a hearth of dolomite, lime, magnesite, or other basic or passive material, and converting it into steel in the presence of a stable basic slag by the action of the flame, with or without the use of ore, and by the addition of the proper recarburizers, the operation being so conducted that the product is cast in a fluid state.

The current belief that the lining is the dephosphorizing agent is a mistake, for the highest function of the hearth is to remain unaffected and allow the components of the charge to work out their own destiny. In practice it is never possible to construct either an acid or a basic bottom so that it is entirely passive, for a slag which is viscous with silica will slowly attack a pure sand bottom, and a cinder which is mucilaginous with lime will gradually eat into a dolomite hearth. For the construction of a permanent bottom, carbon, bauxite, lime, chromite, magnesite and dolomite have been used. Magnesite gives the best results, but is costly, and well-burned dolomitic limestone answers well enough. In some places the stone is used in its natural state, but the better plan is to roast it in a cupola and then grind and mix with tar. The roof and walls being made of silica bricks, it is necessary to have a joint of chromite or other passive material between the acid and the basic work; but at the intense heat of a melting furnace, and in an atmosphere charged with spray of iron oxide, almost any two substances will unite if pressed together, so that the joint which bears the superposed brickwork must be shielded from the direct action of the flame.

SEC. XIb.—*Functions of the basic additions.*—Given a hearth capable of resisting the action of metal and slag, the problem of

the basic furnace is the melting and decarburization of iron as in acid practice, with the additional duty of removing a reasonable quantity of phosphorus and some sulphur. Under the influence of the flame and ore, the phosphorus is converted into phosphoric acid (P_2O_5) which can unite with iron oxide, but the conjunction will be only temporary, for the carbon of the bath reduces the iron, and then the phosphorus in its turn is robbed of its oxygen and returned to the bath. But if lime is added, the acid can form phosphate of calcium, and since the oxide of this element cannot be reduced by the carbonic oxide, the phosphorus is never left without a partner, but forms part of a stable cinder. This oxide of calcium is sometimes added in the form of limestone, the carbonic acid being expelled in the furnace. This entails a considerable absorption of heat, and the melting must be delayed accordingly; but it has a compensating advantage in that the gas, in bubbling through the metal, keeps up a motion which facilitates chemical action, and also that the carbonic acid gives up part of its oxygen to the silicon, phosphorus, carbon and iron.

This oxidizing action allows the use of a greater proportion of pig-iron, and aids in the removal of phosphorus, so that there seems to be good ground for using the stone in its natural state. I believe, however, that it is more economical to put it through a preliminary roasting and reduce by nearly 50 per cent. the amount of basic addition, for the rate of melting is thereby hastened, while the oxidizing effect can be obtained by the use of ore. Ore costs more than stone, but its full value is returned in metallic iron, and, moreover, it is possible to use a greater proportion of pig-iron on account of the reduced quantity of gas evolved, for the oxidation done during melting, either by stone or ore, is limited by the frothing of the stock, and this is determined by the amount of gas evolved in the reactions. Therefore, if ore produces less gas than stone in oxidizing a given quantity of carbon, then more pig can be used with ore than with stone. The reactions are as follows:

Limestone, $CaCO_3+C=2\ CO+CaO$.
Ore, $Fe_2O_3+3\ C=3\ CO+2\ Fe$.

Thus two volumes of gas are formed for each atom of carbon when stone is used, while only one volume is produced with ore.

The available oxygen in the ore is nearly twice as much as in

the same weight of stone, so that by using 500 pounds of burned lime and 500 pounds of ore, there will be the same quantity of basic earth, and the same oxidizing effect, as with 1000 pounds of raw stone, while there will be only half as much gas produced with a contribution of 300 pounds of metallic iron.

SEC. XIc.—*Use of ore with the charge.*—The ore and lime are put into the furnace with the pig and scrap, so that the hearth will be protected during the melting and an active cinder be at work continuously. When high-phosphorus stock is used, the amount of oxidation for a given weight of pig-iron is much greater than in acid practice. Thus, in 10,000 pounds of low-phosphorus iron for an acid open hearth, the oxygen-absorbing power is as follows:

1.0 per cent. silicon=100 pounds Si, absorbing	114.3 pounds oxygen.
3.5 per cent. carbon=350 pounds C, absorbing	466.7 pounds oxygen.
Total oxygen absorption,	581.0 pounds

If pig-iron be used in basic work with the same content of silicon and carbon, but with the addition of 1.00 per cent. of phosphorus, there will be an additional absorptive power of 129 pounds of oxygen, or a total of 710 pounds. With the first mixture there would be 40 per cent. of the work done during the melting (as shown in the preceding chapter), so after melting there would remain 60 per cent. of 581, or 349 pounds of oxygen to be given to the bath. In the second case, the presence of phosphorus will not cause a greater action during melting, but the absorption will be the same, so that, after melting, the phosphoric bath will have an absorptive power of 349+129=478 pounds of oxygen, and there will be one-third more work to do during the period of oreing. These figures explain why there is more oxidation to do with phosphoric iron than with good stock, so that it is advisable to use ore mixed with the charge to perform a part of the work during fusion. On an acid hearth ore is sometimes added with the charge, but there is danger of this oxide uniting with the sand of the hearth. In basic practice the ore can do no harm, for it has little effect on the dolomite.

SEC. XId.—*Chemical history when no ore is mixed with the stock.*—The addition of ore is not necessary when sufficient scrap is available, for the flame will supply oxygen to the metalloids, as

shown by Table XI-A, which gives the average of 17 heats when no ore was used with the charge, and when tests of metal and slag were taken at four different epochs. The heats were similar in character, and the mixing of slags and metals to obtain average re-

TABLE XI-A.

Slag and Metal from Seventeen Basic Heats.

Test.	Metal.				Slag.					
	Composition, per cent.				Composition, per cent.					
	C.	Si.	Mn.	P.	SiO_2.	MnO.	CaO.	MgO.	FeO.	P_2O_5
A	.71	.06	.38	.046	19.21	11.12	42.16	6.64	13.68	5.149
B	.34	.01	.25	.022	16.37	10.36	42.78	7.87	16.29	4.343
C	.12	.01	.22	.013	15.08	9.01	42.16	8.45	20.84	3.350
D	.16	.01	.49	.018	15.75	14.11	39.05	10.40	16.65	2.961

sults is justifiable. Each charge was made up of one-half pig-iron and one-half steel scrap, and contained 2.00 per cent. carbon, 0.40 per cent. silicon, 0.85 per cent. manganese, and 0.20 per cent. phosphorus. Tests of slag and metal were taken as follows:

(*A*) After complete fusion of metal without ore.

(*B*) At beginning of boil, after the addition of 1965 pounds of ore per heat.

(*C*) When the bath was ready for the recarburizer, 775 pounds of ore being added per heat between tests *B* and *C*.

(*D*) After casting.

SEC. XIe.—*Elimination of phosphorus during melting.*—The elimination of phosphorus during melting is a variable, depending upon the conditions of oxidation and the ability of the slag to absorb the phosphoric acid. Table XI-B will show the proportions of carbon and phosphorus that are oxidized during melting under different kinds of practice.

SEC. XIf.—*Composition of slag after melting.*—Neither the percentage nor the amount of elimination during melting is a matter of vital importance, for whatever is left undone during that period will be completed before tapping. In this removal of phosphorus after fusion, the composition of the slag is the important factor, and this will depend upon the amount of silica, and upon the lime added. The supply of silica will determine the quantity of lime, and also the weight of the resultant cinder. If the final slag is to

contain 16.67 per cent. of SiO_2 and 50 per cent. CaO, the basic additions must contain $\frac{50.00}{16.67}$=three times as much available CaO as there is SiO_2 in the charge, and the final slag will weigh six times as much.

TABLE XI-B.

Elimination of Phosphorus and Carbon During Melting.

Group.	Pounds of ore charged with stock, per ton of metal.	Number of heats in group.	Composition of metal, per cent.						Composition of slag after melting; per cent.	
			Phosphorus.			Carbon.				
			Initial.	After melting.	Per cent. elimi-nated.	Initial.	After melting.	Per cent. elimi-nated.	SiO_2.	FeO.
1	none.	17	0.20	.046	77	2.00	.71	65	19.21	13.68
2	none.	4	1.86	.594	67	1.50	.60	60	14.90	und.
3	none.	9	0.19	.023	88	1.80	.27	85	15.55	19.68
4	none.	9	0.19	.072	62	1.80	.78	57	19.98	12.20
5	300	3	2.50	.744	70	3.50	.59	83	11.96	8.61
6	115	6	0.55	.274	50	2.90	1.00	66	30.78	10.71
7	140	7	0.55	.402	27	2.90	1.48	49	34.22	10.95

The composition of the cinder differs considerably, for when good stock is used it may contain over 20 per cent. of silica and still be capable of eliminating the impurities, but when much phosphorus is to be removed, the silica must sometimes be as low as 12 per cent., the proportion of CaO usually varying inversely with the silica. The amount of lime which can be taken up is limited, for at a certain point the slag becomes viscous, particularly when the scorification of the hearth supplies magnesia. Allowing for 10 per cent. of MnO, 8 per cent. MgO, 18 per cent. FeO, and 4 per cent. Al_2O_3, etc., it may be stated that with 12 per cent. of SiO_2 there will be 48 per cent. CaO, while with 20 per cent. of SiO_2 there will be 40 per cent. CaO. In the attainment of this ratio between SiO_2 and CaO the purity of the lime is an important factor, especially when a slag low in silica is needed. Ordinary lime contains a certain percentage of CO_2, and a certain amount of moisture, so that with the usual proportions of earthy impurities it will average about 80 per cent. of CaO.

SEC. XIg.—*Relative value of limes.*—The content of SiO_2 in the lime depends upon the kind of stone used and the care with which the ash of the fuel is kept separate. When a choice must be made between a cheap and impure lime and a more costly article low in silica, the value of each may be calculated by finding the excess of

CaO over what is necessary to satisfy its own acids. Two representative limes are assumed in Table XI-C, both containing 80 per cent. CaO, one with 3 per cent. and the other with 7 per cent. SiO_2, and the computation is made for two different slags. The pure lime is worth 31 per cent. more than the impure when a calcareous slag is to be formed, but if a more silicious cinder is permissible, as in the case when little phosphorus is to be removed, the pure lime is worth only 12 per cent. more.

TABLE XI-C.

Relative Values of Limes with 3.0 and 7.0 Per Cent. of SiO_2.

	Slag A.		Slag B.	
	Lime with 3 per cent. SiO_2.	Lime with 7 per cent. SiO_2.	Lime with 3 per cent. SiO_2.	Lime with 7 per cent. SiO_2.
SiO_2 in slag; per cent.	12.0	12.0	20.0	20.0
CaO in slag; per cent.	48.0	48.0	40.0	40.0
Ratio CaO to SiO_2 in slag	4.0	4.0	2.0	2.0
Total CaO in lime; per cent.	80.0	80.0	80.0	80.0
CaO in the lime which is needed to satisfy its own silica; per cent.				
4.0×3.0	12.0	.....	.....	.....
4.0×7.0	.....	28.0	.....	.....
2.0×3.0	.....	.....	6.0	.....
2.0×7.0	.....	.....	.....	14.0
CaO available for foreign silica; per cent	68.0	52.0	74.0	66.0
Relative value.	1.31	1.00	1.12	1.00

SEC. XIh.—*Basic open-hearth slags.*—The proportions of SiO_2 and CaO are the main points in a basic slag, but other factors exercise an important influence upon the result. Magnesia is always present from the wear of the hearth, but is undesirable, as it makes the slag viscous and has less power to hold phosphorus than lime. Alumina comes from the impurities in the dolomite, lime and ore, but being usually in small amount may be neglected. Manganese is usually present in the stock and serves a useful purpose in conferring fluidity upon the slag. It is also valuable in removing sulphur by the formation of sulphide of manganese, which floats to the top of the metal, where the sulphur, being exposed to the flame, is oxidized and passes away with the waste gases. This action is uncertain, and the explanation is somewhat a matter of supposition, but it seems well proven that manganese, either metallic or in the form of ore, aids in the elimination of sulphur, and the above

theory is in accord with the purification of pig-iron by the addition of spiegel.

All the components enumerated are fixed and determined agents in the transactions. Manganese is sometimes reduced from the slag by the carbon of the bath, and a certain percentage may remain unoxidized in the metal, but aside from this the oxides of aluminum, silicon and manganese exist in the slag in just the quantities that were added with the stock; but there are three other constituents—iron oxide, phosphoric acid, and sulphur—whose presence in the slag is determined by the conditions of manipulation and by the proportions of other constituents. Iron oxide is always present, the exact amount depending upon the reducing power of the carbon of the bath. It matters not whether ore is added before melting, after melting, or not at all; there is a certain content of FeO which is demanded by existing conditions, and that certain content will be present. An exception must be made in the case of ore added after the carbon is nearly eliminated, but aside from this there will be just as much iron oxide lost in the slag when no ore is used as when it has been added in proper quantity, and, therefore, all the ore is clear gain.

The presence of iron oxide in either acid or basic slag is an anomaly, for in an acid charge the oxidation of the silicon and manganese would be sufficient to produce a slag without other aid. Nevertheless, there is a force at work in an acid furnace which is constantly creating a slag with about 50 per cent. SiO_2 and 45 per cent. FeO+MnO. If more FeO is added, the carbon of the metal seizes the oxygen and sets free metallic iron, but the same powerful action which so quickly accomplishes the destruction of this excess is not able to pass much below the limit, even by exposure for hours, without any addition of ore. There is an automatic adjustment to a fixed status which is one of the most wonderful phenomena of chemical physics. The only explanation I can offer is that forces work along the lines of least resistance, so that a slag will seek to combine with anything that promotes fusibility. If given the opportunity, a silicious slag absorbs either bases or silica, but preferably bases, and particularly those which impart the greatest fluidity. This action tends to continue indefinitely, and in an acid furnace, if the heat is not tapped after the carbon is burned, the formation of iron oxide will go on with great rapidity, and the fluidity of the

slag will be increased, in spite of the cutting of the hearth. This latter action is a correcting condition, but is not the controlling influence, as is proven by the small amount of scorification of the hearth during oreing. The real determinant is the carbon of the bath, and there is an equilibrium between the oxidizing power of the flame, the reducing power of the metalloids, and the struggle after fluidity.

In the basic process there is difficulty in making a slag entirely of silicate of lime, for this is more viscous than a slag of the same percentage of silica containing other bases; there is a tendency, therefore, toward the absorption of iron oxide, but this is opposed by a contest on the part of the lime for the possession of the silica, and the result is a decrease in the percentage of iron when there is an increase in lime. Inasmuch as the substitution of CaO for FeO produces a more viscous slag, this would seem to invalidate the theory just advanced, but the effect is due not to a change in the law, but to the action of stronger forces. The more bases present, the less necessity is there for an additional amount, since the weight of silica necessarily remains constant, and, as the reducing action of the metalloids comes into play, the slag begins to be robbed of its iron, which at the same time is its most reducible and its most fusible base. The presence of oxide of manganese in the slag modifies without completely changing the relations just described, for, by furnishing an additional base and imparting greater fluidity, it tends to render the presence of iron oxide less necessary.

SEC. XIi.—*Automatic regulation of fluidity.*—Fluidity is of vital practical importance, for the slag must run freely from the furnace, else the hearth will soon be filled; furthermore, the slag must be so basic that the hearth is not scorified. The two conditions, fluidity and basicity, determine the nature and amount of the basic additions, for the sum of CaO and MgO cannot much exceed 55 per cent. without producing a viscous cinder, neither can the percentage of SiO_2 fall below 10 per cent., unless unusual amounts are present of the oxides of iron, manganese, or phosphorus. This theory of the automatic regulation of fluidity seems to account for a curious relation between the content of SiO_2 and FeO in a large number of basic slags, which are grouped in Table XI-D.

The phosphoric acid was not determined, but it may be taken for granted that an increased proportion of phosphorus in the charge

will give higher phosphoric acid in the cinder, and the table shows that in the case of high phosphorus the combined SiO_2 and FeO runs about 27.5 per cent., with medium phosphorus about 35 per

TABLE XI-D.

Relation Between SiO_2 and FeO in Basic Open-Hearth Slags.*

Group.	No. of heats in group.	Phosphorus in charge, per cent.	Phosphorus in ingot, per cent.	Limits of SiO_2 in slag, per cent.	Composition of slag; per cent.		
					SiO_2.	FeO.	SiO_2+FeO.
1	8	1.85	.068	below 10	9.20	18.45	27.65
2	10	1.85	.088	above 10	12.54	14.93	27.47
3	15	0.19	.016	8 to 12 incl.	10.71	25.31	36.02
4	16	0.19	.017	13 to 14 incl.	13.84	21.81	35.65
5	19	0.19	.020	15 to 16 incl.	15.90	18.21	34.11
6	13	0.19	.023	17	17.32	17.97	35.29
7	16	0.19	.025	18 to 19 incl.	18.94	15.50	34.44
8	12	0.19	.023	20 to 22 incl.	21.57	13.58	35.15
9	7	0.19	.050	23 to 27 incl.	25.48	9.04	34.52
10	16	0.10	.014	10 to 13 incl.	12.28	22.18	34.46
11	14	0.10	.012	14	14.47	22.78	37.25
12	15	0.10	.016	15	15.54	21.10	36.64
13	20	0.10	.017	16	16.46	21.32	37.78
14	19	0.10	.015	17	17.47	19.24	36.71
15	12	0.10	.012	18	18.32	20.02	38.34
16	11	0.10	.018	19	19.41	17.66	37.07
17	14	0.10	.020	20	20.58	14.92	35.45
18	21	0.10	.016	21	21.51	14.58	36.09
19	17	0.10	.019	22	22.46	13.41	35.87
20	11	0.10	.022	23	23.41	12.40	35.81
21	9	0.10	.028	24	24.48	11.05	35.53
22	12	0.10	.042	25 to 29 incl.	26.37	10.58	36.95

cent., and with low phosphorus about 36 to 37 per cent. A difference in manipulation would change the absolute percentages, but the attainment of a certain definite content of FeO+SiO_2 seems assured. This conclusion is verified by an examination of the in-

TABLE XI-E.

Maxima and Minima in Individual Heats in Table XI-D.

Initial phosphorus in charge; per cent.	Slag showing maximum SiO_2; per cent.		Slag showing maximum FeO; per cent.	
	SiO_2.	FeO.	SiO_2.	FeO.
1.85	16.50	6.99	9.46	27.72
0.19	27.35	6.68	9.58	34.47
0.10	29.15	8.27	15.66	34.36

* The full records of the above charges will be found in Sec. 45 of my paper on *The Open-Hearth Process*, in *Trans. A. I. M. E.*, Vol. XXII, p. 436 *et seq.*

dividuals of the original records, for it is found that low SiO_2 is accompanied by high FeO, and *vice versa*. This is shown by Table XI-E, which is composed of the extreme cases of high and low percentages of SiO_2 and FeO, the individual heats which compose the groups in Table XI-D.

It would be wrong to suppose that an increase in SiO_2 has reduced the FeO by simple dilution, for a reduction in FeO from 20 per cent. to 10 per cent. would imply a permanent addition of SiO_2 equal to the entire volume of the slag, and this is absurd. The conclusion seems inevitable that SiO_2 and FeO replace one another in some way, and that one fulfils some function of the other. As FeO is basic and SiO_2 is acid, this function cannot be related to the basicity of the slag, and the only explanation which suggests itself is that both confer fluidity and that there is an automatic regulation of this quality in accordance with the theory before elaborated.

SEC. XIj.—*Determining chemical conditions.*—Just as oxide of iron exists in slag in accordance with favorable conditions rather than with the initial character of the charge, so the content of phosphoric acid is governed by the chemical environment. The capacity of a cinder for phosphoric acid increases with the proportion of bases it contains, and lime is the most potent of these bases, but a certain fluidity is necessary, since a slag which is viscous does not seem to be as effective as one which is rendered fluid by oxide of manganese or iron. Thus, although lime is immeasurably superior to oxide of iron as a dephosphorizing agent, a slag containing a higher percentage of FeO is more efficient.*

One of the more important determinants of the capacity of slag for phosphorus is the phosphorus itself. The absorption of phosphoric acid is not a case of simple solution, like that of salt in water, but a union of acid and base, and each molecule of phosphoric acid which enters the slag decreases its capacity for more. It is impossible to prove this by ordinary averages, for the additions of lime are regulated by the demands of the silica rather than of the phosphorus, and it is a coincidence if the maximum content of phosphoric acid is present. Moreover, the determining conditions vary with each particular combination of the remaining elements, with the intensity of the reducing conditions, and the dura-

* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 446.

tion of the exposure. Thus Table XI-F gives examples of slags produced under abnormal conditions; the samples are from an open-hearth furnace soon after melting, and before an extreme temperature had been reached to give the carbon of the bath its full reducing power.

TABLE XI-F.

Unstable Basic Open-Hearth Slags.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	FeO.	$SiO_2+P_2O_5$.
1	27.58	2.01	10.26	29.54
2	24.05	3.08	18.45	27.13
3	23.45	3.33	9.26	26.78
4	20.26	5.99	10.08	26.25
5	25.21	8.34	11.88	33.55
6	20.60	10.97	10.90	31.57
7	17.31	16.60	12.15	33.91
8	15.07	23.06	10.58	38.13

These slags are selected as instances of high phosphorus for a given silica, and are, therefore, valueless as an indication of what may be expected in practice. They show, however, that there is no such thing as a critical percentage of silica, since a cinder with 37 per cent. SiO_2 may hold 2 per cent. P_2O_5. The slags in Table XI-G

TABLE XI-G.

Normal Basic Open-Hearth Slags.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	FeO.	$SiO_2+P_2O_5$.
1	20.72	6.36	16.20	27.08
2	19.04	8.24	20.16	27.28
3	12.40	13.78	12.60	26.18

are fairer examples of the results of regular work. In both Tables XI-F and XI-G there is a column headed "$SiO_2+P_2O_5$," and the constancy of this total under similar conditions, even with slags of widely varying character, indicates that the total acid content of the slag is the measure of its power to absorb phosphorus.

SEC. XIk.—*Elimination of sulphur.*—A certain proportion of phosphorus is likely to be volatilized by the heat and carried away in the waste gases. This renders futile any attempts to make ac-

curate quantitative calculations, but otherwise the action is of little importance, since it cannot be relied on for purification of the metal. This volatilization occurs in greater measure in the case of sulphur, but here, also, it is impracticable to eliminate any appreciable proportion by this method alone, since volatilization occurs only from the slag, and the action, therefore, presupposes the transfer of sulphur from the metal to the cinder, and this in turn presupposes a condition which will purify the metal without the *ex post facto* intervention of volatilization.

Sulphur can be removed in at least four ways:

(1) By metallic manganese and liquation of sulphide of manganese. The extent of this reaction is uncertain, but usually the addition of 0.60 to 0.75 per cent. of manganese reduces the sulphur content about 0.01 per cent.

(2) By manganese ore, which, being reduced by the metalloids of the bath, furnishes metallic manganese. The ore should be added with the original charge, in order that it may be thoroughly mixed with the metal. It is difficult to isolate the effect of this agent from the action of the basic slag with which it must be associated, but there is no doubt that it aids in the purification.

(3) By a very limey cinder. In a former paper* I gave the results of experiments in removing sulphur by ordinary lime slags.

TABLE XI-H.

Basic Open-Hearth Slags after Melting.

Charge Number.	Initial sulphur, per cent.	Sulphur in metal after melting, per cent.	Composition of slag after melting, per cent.				
			S.	SiO_2.	FeO.	CaO.	MnO.
1546	.43	.28	.28	37.53	10.26	34.53	4.66
1611	.30	.14	.26	32.68	10.17	36.25	und.
1608	.28	.17	.22	31.80	10.98	41.45	und.
1623	.20	.16	.21	33.20	9.45	und.	und.
1642	.20	.14	.21	34.37	6.57	und.	und.
1587	.28	.18	.20	30.26	10.08	45.26	5.42
1642	.20	.15	.18	33.97	11.61	und.	und.
1626	.20	.11	.18	36.43	5.04	und.	und.
1594	.28	.10	.17	32.45	9.36	45.05	5.49
1655	.28	.22	.14	30.68	13.41	39.17	7.15
1620	.20	.09	.14	25.57	8.01	und.	und.
1606	.28	.19	.12	35.79	16.00	33.13	und.
1569	.28	.19	.08	34.05	18.45	35.09	6.25

The cinder, during melting, was kept high in silica to economize lime, and part of this slag was removed after fusion, and fresh lime

* *The Open-Hearth Process. Trans. A. I. M. E.*, Vol. XXII, p. 446.

added. Notwithstanding the high acid content, the slag, after melting, held quite an appreciable proportion of sulphur. The final slag, being richer in lime, removed a greater quantity, and the results seem to show that, as the silica decreases, the capacity for sulphur increases, but the relation is not as regular as might be wished. The records are given in Tables XI-H and XI-I.

TABLE XI-I

Basic Open-Hearth Slags before adding Recarburizer.

Charge number.	Initial sulphur, per cent.	Sulphur, after melting.		Sulphur in ingot, per cent.	Composition of slag before adding the recarburizer, per cent.				
		Slag, per ct.	Metal, per ct.		S.	SiO_2.	FeO.	CaO.	MnO.
1608	.28	.22	.17	.095	.61	12.78	26.91	42.99	und.
1611	.20	.26	.14	.054	.58	10.45	26.19	45.85	und.
1555	.28	.14	.22	.086	.56	12.78	26.91	42.14	4.85
1606	.28	.12	.19	.100	.54	12.90	31.14	36.58	und.
1569	.28	.08	.19	.089	.48	15.90	18.68	und.	und.
1620	.20	.14	.09	.062	.43	16.36	19.98	49.50	und.
1546	.48	.28	.28	.120	.36	18.67	24.84	37.22	4.44
1567	.28	.20	.18	.062	.33	14.85	23.49	45.74	4.54
1564	.28	.17	.10	.089	.33	19.18	16.11	49.98	4.58
1648	.30	.21	.14	.090	.26	17.97	23.94	44.41	und.

(4) By oxychloride of lime. A process has been devised by E. H. Saniter* whereby sulphur is eliminated from basic open-hearth metal by oxychloride of lime. It is important to note that "to attain this result it is necessary, at an early period after the charge is melted, to obtain an exceedingly basic slag, and to add a suitable quantity of calcium chloride to it"; and it is specified that "by a very basic slag is not meant what has hitherto been considered as such, but a step in advance of that with about 50 to 60 per cent. of lime." This point is also insisted upon by Stead,† who states that the chloride is used "in conjunction with an excess of lime over and above what is usually employed." He gives analyses of slag and metal for two charges, and a summary of these is given in Table XI-J. The results of a more complete investigation of one charge are shown in Table XI-K, the data being taken from a paper by Snelus.‡

*On a New process for the Purification of Iron and Steel from Sulphur. Journal I. and S. I., Vol. II, 1892, p. 216; also, A Supplementary Paper on a New Process on Desulphurising Iron and Steel. Journal I. and S. I., Vol. I, 1893, p. 73.

† On the Elimination of Sulphur from Iron. Journal I. and S. I., Vol. II, 1892, p. 260.

‡ Report upon the Saniter Desulphurization Process. Journal I. and S. I., Vol. I, 1893, p. 82.

TABLE XI-J.

Elimination of Sulphur by Calcium Chloride.

Heat.	Composition, per cent.							
	Metal.		Slag.					
	Sulphur.		After adding $CaCl_2$.			At time of tapping.		
	Initial.	In steel.	SiO_2.	CaO.	S.	SiO_2.	CaO.	S.
1	.37	.047	10.75	54.65	1.25	10.20	48.98	.65
2	.17	.055	14.45	44.84	.58	11.75	47.86	.57

TABLE XI-K.

Detailed Data on the Elimination of Sulphur.

Open-hearth charge: 80 per cent. white iron, 20 per cent. scrap, the whole averaging about .30 sulphur.

Time of taking sample.	Composition of metal, per cent.		Composition of slag per cent.		
	C.	S.	SiO_2.	CaO.	S.
After complete fusion	.20	.220	18.80	49.24	.315
1 hour after melting	.09	.181	15.00	49.60	.576
4 hours after melting	.06	.098	11.60	55.64	.659
Steel, 5½ hours after melting .	.10	.040	10.80	57.00	.645

The sulphur after melting is higher than the calculated initial content, but this is probably due to incorrect sampling and to the absorption of sulphur from ore and gas, since the percentage of sulphur in the slag shows that a considerable amount was taken from the metal. After melting, the carbon was reduced to .20 per cent., and one hour later it was .09 per cent., but it was necessary to hold the charge in the furnace for four and one-half hours after complete decarburization, and to dose it with calcium chloride in the proportion of 50 pounds to the ton of metal, in order to remove the sulphur, a delay which is decidedly objectionable. The oxychloride, however, conferred fluidity upon the cinder, and made it possible to carry as high as 57 per cent. of CaO, and it is probable that this increased mobility and corresponding activity rendered the lime more efficacious in absorbing sulphur.

A quantitative investigation on the slags from three of the charges given in Table XI-H showed that about 36 per cent. of

the sulphur was unaccounted for, having probably been carried away in the waste gases. The fact that both sulphur and phosphorus thus escape, in an intangible form and in uncertain quantities, renders quantitative work on basic slags very unsatisfactory. Moreover, a sample of slag is not always representative, for on some heats portions of the basic additions remain sticking to the hearth, while on others old accumulations of such deposits dissolve in a charge to which they do not belong.

SEC. XII.—*Removal of the slag after melting.*—When the stock is properly charged, the greater part of the basic addition becomes an active agent during the melting of the charge. Especially when ore is used the intense action oxidizes a considerable proportion of the phosphorus during the melting, and the slag, after fusion, contains oftentimes a high percentage of phosphoric acid. The idea has occurred to numberless metallurgists that this first slag should be removed, in order to get rid of its phosphorus and silica, and thus give the opportunity for a new and purer slag having a greater dephosphorizing power. There are certain practical difficulties in the way, for the height of the metal in the hearth is always varying with the filling of the bottom and with the frothing of the charge, so that there is danger of losing metal if a tap-hole is opened much below the level of the upper surface of the slag; on the contrary, if the slag is tapped from its upper surface there is no force to the stream, and it is constantly chilling as it runs. In spite of these troubles, the partial removal of the slag is not uncommen. Complete removal can be accomplished by the use of a tilting furnace, for the entire charge can be poured out and only the metal returned to the hearth.

SEC. XIm.—*Automatic formation of a slag of a given composition.*—After removing a large proportion of slag from a heat, it might appear to be difficult to again construct a cinder of just the right composition, but the records in Tables XI-H and XI-I show that such is not the case, for, in the heats there given, a part of the slag was removed soon after melting. Quite a difference will be found between the first and second slags, but the first slag was purposely made high in silica, in order to save lime. When it is required to maintain a similar composition throughout the heat, it can be done in basic as well as acid practice, as shown in Table XI-L. Four-fifths of the lime was added with the charge, and the

remainder, together with 400 pounds of ore, was used after melting, but in spite of the incorporation of this basic material into the slag during the interval between the two stages at which the samples were taken, it will be seen that a uniform composition was maintained.

TABLE XI-L.

Slag Analyses of Twenty-seven Basic Open-Hearth Heats.

Slag.	Composition, per cent.			
	SiO_2.	P_2O_5.	CaO.	FeO.
After melting	14.85	15.58	45.07	9.00
Before tapping	12.40	13.78	45.40	12.60

SEC. XIn.—*Recarburization and rephosphorization.*—Recarburization is carried on in the same way as in acid work. A complicating condition is added when either the stock or the ore contains any considerable proportion of manganese, for the decarburized metal may then hold as much as .20 or .30 per cent. of Mn. Not only must this be allowed for in the final addition, but the bath contains less oxygen under these circumstances, and there will be less loss of metallic manganese during the reaction. There is also danger of rephosphorization, or the return of phosphorus from slag to metal. In the basic-Bessemer this is a source of considerable trouble, but in the open-hearth the recarburizer is almost always added in a solid state and the metal probably contains less oxygen, so that the reaction is less violent. Moreover, during the solution of the ferro, the slag is at work with its dephosphorizing influence, so that the sum total of the reactions may even show a decrease in phosphorus. Other things being equal, it would seem probable that a slag containing a high percentage of phosphoric acid will hold this component less firmly than a purer cinder, and I have tried to illustrate this point* by experiments, the results of which may be summarized as follows:

(1) With slags containing under 5 per cent. P_2O_5 and not over 20 per cent. SiO_2, the rephosphorization need not exceed .01 nor average over zero per cent.

(2) With slags containing from 5 to 10 per cent. P_2O_5 and not

* *The Open-Hearth Process. A. I. M. E.*, Vol. XXII, p. 484.

over 19 per cent. SiO_2, the rephosphorization need not exceed .015 nor average over .005 per cent.

(3) With slags containing from 10 to 15 per cent. P_2O_5 and not over 17 per cent. SiO_2, the rephosphorization need not exceed .02 nor average over .005 per cent.

(4) With slags containing from 15 to 20 per cent. P_2O_5 and not over 12 per cent. SiO_2, the rephosphorization need not exceed .02 nor average over .01 per cent.

In using phosphoric stock it is not safe to presuppose the elimination of phosphorus below .04 per cent. until the carbon has been lowered to .08 per cent. Hence to make rail steel it is necessary to eliminate the carbon to that point and then add the required amount of recarburizer, as in the Bessemer process. It is impracticable to use melted spiegel-iron in open-hearth practice, unless there are a great number of furnaces, because the charges come so irregularly and at such long intervals that a cupola becomes chilled, but it has been found possible to add finely divided carbon in the ladle, its absorption by the metal being so rapid that the results are quite regular.

CHAPTER XII.

SPECIAL METHODS OF MANUFACTURE.

SECTION XIIa.—*Low-phosphorus acid open-hearth steel at Steelton.*—The early history of the open-hearth in the United States is confined to the making of acid steel, very little basic metal being made until after 1890. A large proportion of the output went into boiler plate and quite a quantity into forgings, while there was a considerable tonnage of high-carbon steel. The ordinary grades of boiler steel and forgings were made of stock running from .08 to .10 per cent. of phosphorus, while metal for fireboxes and special forgings, as well as some of the high-carbon steel, was made of low-phosphorus stock, usually a mixture of Swedish pig-iron and charcoal blooms. A certain quantity of low-phosphorus pig-iron was made in America, and during the latter part of the acid epoch a considerable quantity was manufactured of what is known as "washed metal." This is made by treating melted pig-iron in a furnace lined with iron ore and lime and eliminating most of the silicon, sulphur and phosphorus and about half the carbon. The pig-iron is the same grade as is used in the basic open-hearth furnace, and the "washed metal" process is essentially the same as the basic open-hearth process of to-day. It differs from it in the following particulars:

(1) In the basic open-hearth furnace, the bottom is made as durable as possible and it is desired that it shall not be cut away by the action of the metal and slag. The iron ore needed to oxidize the metalloids and the lime to make a basic slag are both added with the charge, and the reactions take place in a definite way very similar to the fusions made by a chemist in a platinum crucible, the crucible playing no part in the reaction. In the washed metal process the bottom is not durable, but is intended to supply the ore and lime to oxidize the metalloids and give a basic slag.

(2) The washed metal furnace is not allowed to reach a very high

temperature, because the slag is not stable and at a higher temperature the hearth would be cut away, the reactions would be more violent and the phosphorus would leave the slag and go back into the metal. In the open-hearth furnace the phosphorus does not go back, because the slag contains a sufficient proportion of lime to make a permanent compound with the phosphorus, so that it is not readily reduced by carbon. Such a slag needs a high temperature for complete fusion and this temperature cannot well be carried in the washed metal furnace.

(3) The washed metal furnace is tapped when the metal contains about 2 per cent. of carbon, because if the carbon be run down any lower a much higher temperature would be needed, and because this kind of product suits the demands of the trade.

The low-phosphorus open-hearth steel of former days was made from either low-phosphorus pig-iron and charcoal blooms or washed metal and charcoal blooms, and this washed metal was the product of a basic process. The charcoal blooms were also of basic origin, because they were made by the action of a basic oxidizing slag on melted metal.

After the introduction of the basic open-hearth process it became possible to buy in the open market a supply of low-phosphorus steel scrap at a moderate price, and this scrap rapidly took the place of the high-priced charcoal blooms and stopped their manufacture. Thus while the basic open-hearth furnace rendered it possible to produce a low-phosphorus steel much cheaper than it had ever been produced before, it also cheapened the cost of low-phosphorus acid open-hearth steel. This is true, however, only to a certain extent, for the basic furnaces themselves need scrap and use most of the available supply. Moreover, the low-phosphorus pig-iron, which must be used, costs from three to five dollars per ton more than the ordinary Bessemer grade.

In order to overcome these difficulties we have introduced at the works of The Pennsylvania Steel Company an adaptation of the old washed metal process. The pig-iron is charged in a basic lined furnace, and almost all of the silicon and phosphorus and part of the sulphur and carbon are eliminated. At this stage it is washed metal, and in olden times would have been run out in chills and afterward charged into the acid furnace, but in this new practice it is poured into a ladle, and, while still fluid, is poured into the

acid furnace. A certain amount of scrap may be used in the basic furnace, or in the acid furnace, or in both; but the main point is to have no basic slag enter the acid furnace and to be sure that the dephosphorized metal, when it goes into that furnace, shall contain as much carbon as is usually present in an acid bath after the stock is melted. We thus have the transferred charge starting on its acid journey in the same condition as if it had been melted in the acid furnace, so that the reaction, the slag, and the whole history from that moment, are the reactions, the slag and the history of the acid open-hearth furnace.

TABLE XII-A.

Metal and Slag in the Acid Furnace when Washed Metal is Transferred in a Molten State from a Basic to an Acid Furnace.

Note: Samples over 1.10 per cent. in carbon omitted.

Heat No.	Composition of Metal, per cent.				Composition of Slag, per cent.				
	C	Si	S	P	SiO_2	MnO.	FeO	MnO+FeO	$\frac{SiO_2+MnO+}{FeO}$
A.....	1.00	.02	.088	.025	50.57	12.16	32.04	44.20	94.77
	.71	.01	.037	.025	49.91	11.08	32 58	43.66	93.57
	.30	.08	.037	.029	55.76	9.75	28.05	37.80	93.56
	.19	.02	.088	.025	55.44	9.22	30.15	39.37	94.81
B.....	.80	.08	.025	.009	47.71	3.46	44.64	48.10	95.81
	.31	.08	.020	.008	53.90	4.30	37.62	41.92	95.82
	.21	.02	.021	.008	51.50	7.67	35.55	43.22	94.72
C.....	.95	.02	.020	.019	51.08	12.94	29 79	42.73	93.81
	.70	.02	.020	.019	45.38	9.04	40.05	49.09	94.47
	.54	.08	.021	.022	50 01	9.10	35.55	44.65	94.66
	.23	.08	.020	.021	52.61	10.92	30.87	41.79	94.40
D.....	.77	.08	.026	.010	58.52	10.92	28.98	39.90	98.42
	.45	.08	.029	.011	52.22	8.34	32.58	40.92	93.14
	.31	.08	.029	.012	52.50	7.36	36.54	43.90	96.40
E.....	.90	.02	.040	.034	51.82	6.52	37.44	43.96	95.78
	.60	.01	.034	.031	50.27	7.44	38.79	46.23	96.50
	.17	.02	.034	.030	51.66	5.51	39.51	45.02	96.68
F.....	1.09	.02	.027	.008	42.50	9.89	41.76	51.65	94.15
	.72	.02	.027	.008	51.20	10.17	33.75	43.92	95.12
	.24	.02	.027	.008	56.61	9.60	29.61	39.21	95.82
G.....	.75	.01	.028	.010	46.95	11.46	39.24	50.70	97.65
	.46	.01	.028	.010	51.02	10.44	33.98	44.37	95.39
	.26	.01	.029	.010	54.80	11.58	28.17	39.75	94.55
H.....	.95	.01	.022	.026	42.21	14.34	37.98	52.32	94.53
	.62	.02	.024	.030	49.66	12.65	32.65	45.30	94.96
	.25	.02	.023	.028	50.28	11.72	31.41	43.13	93.41
I.....	.70	.02	.030	.011	45.16	15.14	35.46	50.60	95.76
	.43	.02	.028	.010	47.65	9.89	36.99	46.88	94.53
	.22	.08	.029	.011	57.23	9.36	26.91	36.27	93.50

This practice is not feasible in most open-hearth plants, but the demands of engineers for pure acid open-hearth steel made it necessary to equip a plant to supply this special product. In order to show that the composition of the metal and slag in the transfer process is the same as in the usual acid furnace, I had samples taken from the bath during different stages of the operation. The metal was tapped from the basic furnace when it contained from 2.50 per cent. to 3.50 per cent. of carbon, and transferred in a molten state to the acid furnace. When the carbon was about 1.00 per cent. the taking of samples was begun. It is seldom that a charge in an acid furnace is higher than this when it is melted, so that the records may be compared with the ordinary acid heat after complete fusion.

The results on nine heats are given in Table XII-A, and they may be compared with Table X-B. This latter table shows, under Group I, the composition of slag and metal as found some years ago in an acid furnace running on the usual pig, scrap and ore process. A comparison of the results is shown in Table XII-B.

TABLE XII-B.

Comparison of Data in Tables X-B and XII-A.

		Group I. Table X-B	Transferred Steel.		
			Min.	Max.	Av.
After Melting.....	Carbon in metal.....	.54	.70 to	1.09	.88
	SiO_2 in slag.....	50.24	42.21 to	53.52	47.95
	FeO+MnO.....	45.58	42.78 to	52.32	47.13
	SiO_2+FeO+MnO.....	95 82	98.42 to	97.65	95.08
End of Operation.....	Carbon in metal..... ...	13	.17 to	.31	.23
	SiO_2 in slag.....	49.40	49.40 to	50.28	53.62
	FeO+MnO.....	46.29	36.27 to	45.02	41.30
	SiO_2+FeO+MnO.....	95.69	93.41 to	96.68	94.92

The last sample was not always taken just before tapping. Thus in heat D, Table XII-A, the final carbon was not .31 per cent., but the last sample was taken at that point and for the purposes of the investigation this was deemed sufficient. The composition of the slag, both at the earlier and later periods, corresponds to that in former experiments, and if samples had been taken with lower carbons to correspond with the .13 per cent. in Group I, Table X-B, there would have been even a still closer resemblance, as the percentages of metallic oxides would probably have increased.

SEC. XIIb.—*The pig-and-ore basic process.*—The question of working a large proportion of pig-iron is one which all large works are driven to face. In an ordinary stationary furnace the use of an entire charge of pig-iron is objectionable on account of excessive frothing of metal and slag. From the time that the metal is thoroughly melted, when it may contain about 3 per cent. of carbon, until the proportion is reduced to about 1½ per cent., the bath resembles soda water more than pig-iron, and it tries to flow out of the doors and to occupy about twice the room it should. In Steelton we have solved the difficulty caused by this frothing by using the tilting furnace rotating about a central axis. (See Chapter VII.) The pig-iron is brought in a melted state from the blast furnace and poured into the open-hearth furnace, a sufficient quantity of iron ore and lime being added. During the combustion of silicon no violent reaction occurs, but immediately afterward a general movement takes place, whereupon the furnace is tipped over until the metal is thrown away from the doors and up on the back side. In this way the capacity of the furnace is practically doubled, while the flame enters and goes out as usual. The furnace is kept in this position for two or three hours, until the bath has quieted down. Meanwhile the slag is trying to froth out of the ends of the furnace and down the ports, but to do so it must flow over the open joint between the port and the furnace. This joint is not wide, but special provision is made to allow the slag to run out through a small hole and fall down beneath the end of the furnace in a slag pit. In this way a considerable quantity is removed and the time of operation lessened.

At some works the slag is removed by a small tap-hole or through the regular door, but under these circumstances the stream continually chills and must be carefully tended. In the arrangement above described there is little tendency to chill, for the flame is constantly playing back and forth through the ports and the slag opening is in the immediate course of the hottest flame. This practice of using direct metal has been in more or less continuous use for several years on furnaces of fifty tons capacity. Working in this way the iron of the ore is reduced in such quantity that the product of steel, counting both ingots and scrap, exceeds the weight of pig-iron charged by from 4 to 6 per cent. when the charge is entirely pig-iron.

It is not necessary that the iron should be brought in a melted state from the blast furnace, as the same procedure can be followed when it is charged cold. Table XII-C shows the results from two series of heats, in one of which most of the metal was charged cold, while in the other the metal was all fluid. In these series especial care was taken to have the weights accurate and to know the composition and weight of the slag produced. I do not consider that any results on loss are worth recording unless the exact amount of pure metallic iron put into the furnace is known and unless this equals the weight of metallic iron in the ingots, the scrap and the slag. In addition to this it is well to know the total amount of CaO put into the furnace in the form of limestone, burned lime or dolomite, and see whether this agrees with the amount of CaO which is indicated by the weight and composition of the slag. In the following two series these conditions were attained and the amount of CaO used was found to check the records of the slag, while the balance sheet of metallic iron agrees within one-fifth of one per cent. In individual heats no such accuracy can be obtained,

TABLE XII-C.

Record of "All-Pig" Basic Open-Hearth Heats at Steelton.

	First Series. Pounds.	Second Series. Pounds.
Liquid metal (1.4 per cent. Si)...	156,200	405,287
Iron cast in chills.....	352,210	.....
Iron cast in sand.....	36,020	.....
Recarburizer.....	3,600	4,725
Total metal charged.....	548,030	410,012
Ore (66.3 per cent. Fe).....	144,100	116,300
Ingots.....	551,200	429,000
Scrap.....	13,800	1,355
Total steel.....	565,000	430,355
First slag.....	27,130	73,600
Second slag.....	17,140	41,500
Total slag.....	44,270	115,100

Composition of first slag.....	SiO_2....	24.04	23.67
	CaO....	11.84	18.14
	Fe)....	41.63	45.00
Composition of second slag..	SiO_2....	11.78	16.14
	CaO....	41.90	37.26
	FeO....	26.93	25.94

and it is often impossible on a series of heats, as the wearing of the hearth or the accumulation of slag will give a gain or a loss. In Table XII-C the term "first slag" signifies that which flows through the port opening, and is thus removed from the furnace during the progress of the operation, while "second slag" means the cinder from the furnace at the time of tapping.

Taking as a basis the weight of pig-iron and recarburizer, the weight of ingots and scrap together was 103.1 per cent. in the case of the cold metal, and 104.95 per cent. with liquid metal. These figures neglect entirely the weight of ore charged, but it is customary to speak of such practice by saying that the gains were 3.1 per cent. and 4.95 per cent. respectively. This subject will be again referred to in other sections of this chapter.

In the case of the cold pig, the first and second slags together carried away 7.3 per cent. of all the metallic iron put into the furnace, including the iron in the ore. In the case of the melted iron, this loss was 7.4 per cent. The silicon in the pig-iron was 1.4 per cent., which is high for basic practice. Had it been lower there would have been less silica produced, less lime would have been necessary, less slag would have been produced, and less iron would have been lost in the cinder. The slag is not exactly proportionate to the silicon in the iron, as there are other sources from which silica is supplied, but had the silicon in the pig-iron been reduced one-half, to a content of 0.70 per cent., the volume of slag would have been only two-thirds as much, and it would carry away less than 5 per cent. of the total iron in the charge, which would mean a gain of 2.5 per cent. in the weight of ingots over the actual practice and give a total gain in weight of 7.5 per cent. Less ore would be required with lower silicon, but on the other hand, a lower percentage of silicon means a higher content of metallic iron in the pig-iron, which is bound to show itself in a greater product.

SEC. XIIc.—*The Talbot process.*—The last section described the difficulties encountered in the use of the pig-and-ore process in a furnace that cannot be tilted while in operation. A way of overcoming this trouble has been carried out by Mr. Talbot.* A tilting furnace is used, and when the charge is ready to tap, a portion of the steel, and a portion only, is poured into the ladle and cast into ingots. The remainder is kept in the furnace and a new supply of

* *Journal I and S. I.*, Vol. I. 1900.

melted iron added to it. Taking the case of a 50-ton furnace and assuming that thirty tons of low-carbon metal is retained and twenty tons of pig-iron added, the average of the new bath will contain about 1.5 per cent. of carbon, which will be quite a manageable mixture.

Considerable stress is laid on the addition of iron oxide before the addition of pig-iron in order to create a violent reaction and quickly oxidize the metalloids, and it is claimed by Mr. Talbot that this oxidation produces heat. It will be shown in Section XIIe that this is a great mistake and that the reaction absorbs much energy. Were it not so, there would be no difficulty in eliminating

TABLE XII-D.

Reactions in the Talbot Process.

Note: For convenience I have started both heats at 12:00 o'clock.

Time.	Sample.	Weight lbs.	Composition of Metal.					Composition of Slag.			
			C	S	P	Mn	Si	Fe	SiO_2	P_2O_5	MnO
	Heat No. 254—										
12:00	Slag from previous heat.	.....	...	....	.....	....	....	10.49	11.68	13.26	7.00
12:30	Scale	3,600	....	....	.....	....	....	.....	.....	.....	.....
1:05	Bath and slag	90,000	0.06	.051	.026	0.08	....	25.57	8.68	9.44	.....
1:10	Cupola iron	23,700	3.80	.082	1.012	0.26	0.18	.....	.....	.....	.....
1:18	Bath and slag	113,700	0.49	.053	0.132	0.15	....	11.87	12.10	16.45	.....
1:20	Ore	2,300	..	....	.....	....	....	.....	.....	.....	.....
1:20	Limestone	1,440	...	....	.....	....	....	.....	.....	.....	.....
1:35	Bath and slag	113,700	0.38	.056	0.111	0.14	....	10.39	12.62	17.05	.....
1:40	Cupola iron	12,000	3.80	.065	0.980	0.43	0.25	.....	.....	.....	.....
1:47	Bath and slag	125,700	0.71	.057	0.144	0.14	....	10.71	12.32	15.56	.....
1:50	Cinder	2,500	....	....	.....	....	....	.....	.....	.....	....
1:50	Limestone	2,250	....	....	.....	....	..	.....	.....	.....	.....
3:30	Ore	1,100	....	....	.....	....	....	.....	.....	.....	.....
3:30	Limestone	1,000	....	....	.....	....	....	.....	.....	.....	.....
3:40	Manganese Ore	800	....	....	.....	....	....	.....	.....	.....	.....
4:30	Bath and slag	125,700	0.07	.025	0.035	0.17	....	13.95	.....	.....	.....
4:35	Cupola iron	3,000	3.80	.065	0.980	0.43	0.25	.....	.....	.....	.....
4:40	Bath and slag	128,700	0.11	.033	0.041	0.18	....	11.59	.....	.....	.....
4:40	Steel and slag tapped	.....	0.16	.050	0.036	0.50	....	11.81	11.55	12.03	7.83
	Heat No. 306—										
12:00	Slag from previous heat.	.....	....	....	.....	....	....	14.29	11.70	12.03	5.12
12:40	Scale	3,800	....	....	.....	....	....	.....	.....	.....	.....
1:10	Bath and slag	95,000	.06	.053	0.045	0.06	....	43.37	5.18	4.17	.....
1:15	Cupola iron	14,000	3.80	.052	0.976	0.24	0.36	.....	.....	.....	.....
1:25	Bath and slag	109,000	0.11	.052	0.062	0.06	....	21.17	11.22	10.82	.....
1:40	Bath and slag	109,000	0.07	.057	0.049	0.05	....	23.16	9.95	9.83	.....
1:45	Cupola iron	17,200	3.80	.057	1.004	0.26	0.35	.....	.....	.....	.....
2:00	Bath and slag	126,200	0.34	.052	0.111	0.08	....	18.05	12.08	12.45	.....
2:05	Cinder	2,300	....	....	.....	....	....	.....	.....	.....	.....
2:05	Limestone	2,700	....	....	.....	....	....	.....	.....	.....	.....
3:50	Manganese ore	400	....	....	.....	....	....	.....	.....	.....	.....
4:35	Bath and slag	126,200	0.07	.049	0.022	0.08	....	21.54	.....	.....	.....
4:40	Cupola iron	6,100	3.80	.057	1.004	0.26	0.35	.....	.....	.....	.....
4:50	Bath and slag	132,300	0.07	.047	0.030	0.10	....	16.28	.....	.....	.....
4:55	Steel and slag tapped	.....	0.14	.050	0.038	0.45	....	18.39	10.94	12.26	5.44

silicon and carbon in the open-hearth furnace by ordinary methods, for a charge can be decarburized with great rapidity by shoveling ore into the furnace continually; the reactions take place and the silicon and carbon are oxidized as fast as can be desired, but this cannot be continued because there is such an absorption of heat that the bath becomes cold. It is difficult to see how the time necessary for decarburization can be shortened by preheating and melting the ore, and having a violent reaction with a consequent chilling. The decarburization itself will take place in less time, but the total time necessary to melt the ore, to complete the reaction, and to heat the charge after the reaction will probably be longer than if the ore were added after the pig-iron is charged.

Table XII-D is condensed from Mr. Talbot's paper showing the history of the metal and slag in the furnace. There are five heats given in full in his paper and one other heat in part, but I have quoted only two, as they are representative of all. Mr. Talbot lays much stress on the gain in weight from the ore, but it is a mistake to regard this as characteristic of the method. Section XIIg will take up this subject, while Sections XIIe and XIIf also bear upon the matter.

TABLE XII-E.

Elimination of Sulphur in Talbot Furnace.

Heat.	Rate of Production.		Elimination of Sulphur.	
	Weight of ingots; lbs.	Time from tap to tap. Hours-Min.	Calculated average sulphur in metal charged.	Sulphur in finished steel.
264	57,405	3—50	.041	.038
264	39,100	4—25	.048	.038
265	39,085	4—40	.058	.050
266	37,410	4—55	.054	.050
466	28,650	4—30	.049	.054
Total	191,650	22—20	.....	.....
Rate per 24 hours	92 tons.	.....	.....	.....

Table XII-E shows that there was very little elimination of sulphur in any of the heats; the slag was kept fluid and not very basic, and under these conditions the furnace will run much faster and make more product than if a better steel is made. Three out of the five heats would not fill the standard American specifications for boiler plate. It may be urged that there was no necessity of

elimination, but this will hardly apply to the results given on pages 59 and 61,* showing two weeks' working and the composition of fifty-five heats. Of these the sulphur content was as follows:

7	heats	between	.040	and	.049	per	cent.
20	"	"	.050	"	.059	"	"
21	"	"	.060	"	.069	"	"
3	"	"	.070	"	.079	"	"
3	"	"	.080	"	.089	"	"
1	heat				.090	"	"

If sufficient time had been allowed for the elimination of sulphur, and if during all this time the slag had been more basic, more viscous and more voluminous, the time would have been increased and the amount of fuel greater. The iron was melted in a cupola, and this raised the sulphur, but a blast furnace could not be relied upon to furnish a better iron than was used.

The Talbot process has an advantage in the greater output from a given ground area, a vital matter in a constricted city works. It is also of value where the open-hearth furnaces must run almost wholly on pig-iron containing a high percentage of phosphorus, as at Frodingham, England.

SEC. XIId.—*The Bertrand Thiel process.*—There has been developed at Kladno, in Bohemia, a system of handling phosphoric pig-iron. There were two open-hearth furnaces on different levels, making it possible to tap from one furnace into the other by means of a runner. The higher furnace is used to remove the silicon, part of the carbon and most of the phosphorus, while the second completes the process. Many years ago, when the practice had not been reduced to precision, Mr. Bertrand published† the results of twelve heats, which show that the metal was in the first furnace an average of 4 hours and 50 minutes, and in the second 2 hours and 20 minutes.

The proportions of pig-iron and scrap are unimportant, but it is considered best to charge mostly pig-iron in the first furnace, using sufficient ore to give a good reaction and oxidize the metalloids, and to charge some scrap in the second furnace. The stock in the second furnace is partly melted when the steel runs to it, and there is a quick and violent reaction. Care is taken to allow no slag to run to the second furnace, and the phosphorus, which has been elimi-

* *Loc. cit.* † *Journal I. and S. I.*, Vol. I, 1877.

nated in the first furnace, is kept out of the operation from that time forward. The second furnace starts with a semi-purified metal and a new and clean slag. Following is a summary of the data given by Mr. Bertrand:

	Metal.				Slag.		
	C	P	Si	Mn	SiO_2	P_2O_5	FeO
Pig iron	3.8	1.6	1.0	1.0	.....	.....	.....
From first furnace	2.2	0.4	.05	0.5	26.30	12.23	9.49
From second furnace	.....	.....	.....	.....	13.23	11.78	14.26

The average sulphur in the steel is .042 per cent., but all the pig-iron contained less than .05 per cent., so there was little elimination of this element. The average phosphorus in the steel is .067 per cent. The twelve heats may be divided as follows, in their content of this element:

1	heat				.021	per	cent.
2	heats	between	.03	and	.04	"	"
2	"	"	.04	"	.05	"	"
2	"	"	.05	"	.06	"	"
1	heat				.075	"	"
1	"				.086	"	"
1	"				.098	"	"
1	"				.170	"	"

Of these twelve heats one heat was so high in phosphorus that it could not be sold in America, while seven more were above the standard for American basic steel. Attention is called to this fact to illustrate that on the continent of Europe the specifications on structural steel are in no manner as severe as in America. In this country a charge known to contain .17 per cent. of phosphorus would be remelted and never spoken of as steel. On the other side it needs only to pass certain physical tests and it will be accepted by Lloyds, in England, or by a hundred engineers on the Continent. Later results on Kladno practice have been given by Mr. Hartshorne,* who has kindly given me the original reports. The pig-iron was nearly all molten and carried about 1.5 per cent. of phosphorus, while the average metal from the primary furnace ran as follows in phosphorus:

* *Trans. A. I. M. E.*, Feb. 1900.

17	heats	below			.10	per	cent.
45	"	between	.10	and	.20	"	"
10	"	"	.20	"	.30	"	"
5	"	"	.30	"	.40	"	"
2	"	"	.40	"	.50	"	"
1	heat	not given.					
80							

The slags from the primary furnace contained from 20 to 23 per cent. of phosphoric acid and the following proportions of iron (Fe):

4	heats	between	6	and	7	per	cent.
22	"	"	7	"	8	"	"
16	"	"	8	"	9	"	"
12	"	"	9	"	10	"	"
7	"	"	10	"	11	"	"
2	"	"	11	"	12	"	"
1	heat	"	12	"	13	"	"
4	heats	"	13	"	14	"	"
3	"	"	14	"	15	"	"
1	heat	"	17	"	18	"	"
8	heats	not given.					
80							

During two weeks the furnaces made an average per twenty-four hours of 7.6 heats of 12.3 tons each, or 94 tons per day for the two furnaces, the maximum capacity of the larger being 13 tons. The phosphorus in the steel was as follows:

18	heats	below	.01	per	cent.		
24	"	between	.01	and	.02	per	cent.
21	"	"	.02	"	.03	"	"
8	"	"	.03	"	.04	"	"
2	"	"	.04	"	.05	"	"
4	"	"	.05	"	.06	"	"
1	heat	"	.07	"	.08	"	"
1	"	"	.08	"	.09	"	"
1	"	"	.11	"	.12	"	"

In a private communication from Mr. Bertrand I received corroboration of the foregoing practice and he gave the results on two heats, one made from an iron with about 1.30 per cent. of silicon, and the other with 0.50 per cent. The higher silicon necessitates a larger addition of lime and reduces the phosphoric acid in the slag from the primary furnace, this being an objection when the slag is to be sold as a fertilizer. The results are given in Table XII-F. Mr. Bertrand states that manganese in the pig-iron has an important bearing on the elimination of phosphorus, and saves time, as the slag is more liquid and the hearth remains cleaner after tapping. When there is no manganese in the pig-iron the phos-

phorus may be reduced to .02 per cent., but by having 2 per cent. of manganese the phosphorus may be worked down to 0.005 per cent. in the steel. Such a low content is not unusual in America, but the pig-iron at Kladno carries 1.5 per cent. of phosphorus. The Bertrand Thiel process would seem to be most applicable to pig-irons containing a considerable quantity of phosphorus, for the slag from the primary furnace is then of considerable value as a fertilizer. In the northern part of the United States, where there are no pig-irons containing high percentages of phosphorus, this primary slag would be of no value, but in the South or in Cape Breton it might be an important by-product.

TABLE XII-F.

Practice at Kladno.

Private Communication, February, 1901.

	Composition of Metal. Per cent.					Composition of Slag. Per cent.		
	C	Si	Mn	P	S	SiO_2	P_2O_5	Fe
Heat A—Primary furnace:								
At charging	3.50	.50	.47	1.35	.....	.....	.....	.....
1 hr. after charging	3.45	.15	.42	.93	.....	20.00	15.67	11.20
2 hrs. 20 min. after charging, transferred to second furnace	2.50	.04	.10	.09	.....	19.16	18.88	6.00
Secondary furnace:								
1 hr. after transfer	.35	.02	.05	.02	.....	14.66	9.70	18.00
2 hrs. after transfer, tapped	.15	.02	.32	.01	.....	13.00	4.99	13.50
Heat B—Primary furnace:								
At charging	3.50	1.30	.39	1.25	.025	.....	.....	.....
1 hr. after charging	3.50	.31	.20	.99	tr	26.00	10.87	13.00
2 hrs. 10 min. after charging, transferred to second furnace	2.70	.01	.06	.17	tr	24.33	15.33	6.00
Secondary furnace:								
1 hr. after transfer	.31	tr	.10	.02	tr	13.33	14.40	11.00
2 hrs. after transfer, tapped	.16	tr	.....	.02	tr	11.43	5.67	15.75

SEC. XIIe.—*The heat absorbed by the reduction of ore.*—It has been stated in Section XIIc that the reduction of iron ore by melted pig-iron does not create heat, but absorbs it, and this can be proven by finding the heat produced by the oxidation of the silicon and carbon, and the heat absorbed in the dissociation of the iron oxide. Inasmuch as it has been stated that Mr. Talbot is in

error* in supposing that this reaction produces heat, it may be well to take the data given by Mr. Talbot showing the composition of the pig-iron and of the slags produced. It will therefore be assumed that the pig-iron contains 1.00 per cent. of silicon and 3.75 per cent. of carbon, and one ton will be taken as a basis. It will also be assumed that the ore is pure ferric oxide (Fe_2O_3) and the problem is to find how much ore is to be added. It is easy to calculate how much oxygen is necessary to burn the silicon, but in addition to this a certain amount of FeO will combine with the SiO_2 to form a slag, and the relative proportions of these two substances depend upon many conditions. In the acid furnace it would not be far wrong to assume that equal weights would be called for, a condition roughly expressed by the formula 5 SiO_2 4 FeO. In the basic furnace the conditions are more complicated, but the relation of SiO_2 and FeO is about the same as in the acid slag. In the present case there is no need to theorize; we are discussing the use of oxide of iron in the Talbot process, and in the description of this process the composition is given of thirteen different slags after the reaction with iron oxide is completed. Taking the average, we have the following:

SiO_2=12.75 per cent.=5.95 per cent. Si.
Fe=15.13 per cent.

Thus when iron oxide reacts upon pig-iron, under the conditions related by Mr. Talbot, the silica from the oxidation of silicon and from other sources enters the slag and carries ferrous oxide with it in such proportions that 5.95 kilos of silicon accompany 15.13 kilos of metallic iron, which is in the proportion of 10 kilos Si to 25.43 kilos Fe. The relative weights will be as follows:

10 kilos Si=25.43 kilos Fe=32.69 kilos FeO=36.33 kilos Fe_2O_3

For every ton of pig-iron containing one per cent. or 10 kilos of silicon, the slag will require 32.69 kilos of ferrous oxide (FeO), while 36.33 kilos of ferric oxide (Fe_2O_3) must be added to supply it.

* For Mr. Talbot's views see *Journal I. and S. I.*, 1900, p. 38. I quote two representative passages: "And thus facilitates rapid chemical action, by which more heat is produced." "It will be seen that both the reducing and heat giving power of these constituents is not a mere piece of theory, but a practical fact." It may be noted that Mr. Bertrand at Klando recognises the great cooling effect of ore reactions.

Simple subtraction shows that the reduction of 36.33 kilos Fe_2O_3 to 32.69 kilos FeO sets free 3.64 kilos of oxygen which unites with the silicon. But 10 kilos of silicon demand 11.43 kilos of oxygen, and therefore 11.43—3.64=7.79 kilos of oxygen must be supplied by further additions of ore, and since we have already satisfied all the demands of the slag, these further additions must be reduced to the state of metallic iron. These 7.79 kilos of oxygen therefore call for the addition of 25.97 kilos of Fe_2O_3, producing 18.18 kilos of metallic iron.

The statement, therefore, is as follows:

1000 kilos pig-iron contain 10 kilos of silicon.
This silicon requires 11.43 kilos of oxygen.

The 11.43 kilos of oxygen are supplied by ferric oxide, part of which is reduced to metallic iron, while the other part is reduced from Fe_2O_3 to FeO, this latter oxide combining with the silica and entering the slag. The amount of iron reduced to the metallic state has been shown to be 18.18 kilos, and the amount of heat absorbed in dissociating this from oxygen will be equal to the amount of heat formed by its union with oxygen, which will be $18.18 \times 1746 = 31{,}742$ calories. The amount of iron present in the slag as FeO has been shown to be 25.43 kilos, and the amount of heat absorbed in converting this iron from the state of Fe_2O_3 to the state of FeO will be the difference between the amount of heat produced by burning this same amount of Fe to the state of FeO and by burning it to Fe_2O_3. This is as follows:

$$25.43 \times (1746 - 1173) = 14{,}571.$$

The total absorption of heat is as follows:

	Calories.
From Fe reduced to metallic state	31,742
From the reduction of Fe_2O_3 to FeO	14,571
Total absorption	46,313

The total production of heat will be the amount formed by the oxidation of 10 kilos of silicon plus that created by the union of the resulting silica with oxide of iron, the account standing thus:

	Calories.
Heat produced by oxidation of 10 kg. of silicon.....	64,140
Heat produced by union of 21.4 kg. SiO_2 with FeO..	3,317
	67,457
Absorption by reduction of iron oxides.....	46,313
Net heat produced.....	21,144

Oxidation of carbon:

Making the same assumptions as in the calculation of silicon, we have the following: 3.75 per cent. of 1000 kilos=37.5 kilos carbon, requiring 50.0 kilos oxygen. 50.0 kilos oxygen require 166.7 kilos Fe_2O_3. 166.7 kilos Fe_2O_3 contain 116.7 kilos Fe, and the heat absorbed in dissociating 166.7 kilos Fe_2O_3 will be the same as the heat created in burning 116.7 kilos Fe to Fe_2O_3, which is

$$116.7 \times 1746 = 203{,}758 \text{ calories.}$$

The heat produced will be the amount created by the burning of 37.5 kilos carbon to carbonic oxide (CO), which is $37.5 \times 2450 = 91{,}875$. The net result, therefore, of the oxidation of the carbon by ferric oxide is as follows:

	Calories.
Heat absorbed	203,758
Heat created	91,875
Net heat absorbed.....	111,883

Silicon and carbon together:

The combined effect of the oxidation of the silicon and carbon has been shown to be as follows:

	Calories.
Heat absorbed in burning carbon.....	111,883
Heat created in burning silicon.....	21,144
Net heat absorption.....	90,739

Two other factors must be taken into consideration. When one kilogram of carbon unites with metallic iron the combination produces 705 calories and the union of 1 kg. of silicon with iron produces 931 calories.* Conversely, when by the reaction of ore upon the bath the carbon is taken away from the iron, there must

* E. D. Campbell; *Journal I. and S. I.* May, 1901.

be a similar absorption of energy. In the present case it will be as follows:

Absorbed by silicon.....	10×931=	9,310
Absorbed by carbon.....	87.5×705=	26,438
Total		35,748
Brought down from above.....		90,739
Total absorption		126,487

To translate these figures into a simpler form it has been shown that if the metalloids in molten pig-iron are to be oxidized by iron ore alone without assistance from the flame of the furnace, then every ton (2240 pounds) of pig-iron will require 500 pounds of iron ore, and the reaction will absorb so much heat that the metal will be 770° C. (say 1380° F.) colder at the end of the work. Of this total of 500 pounds of ore, 367 pounds will be taken care of by the carbon, while 80 pounds will furnish the oxide of iron to form a slag.

This assumes that the ore is added in a liquid state, so that no heat is necessary to heat or melt the addition. It does not assume that the carbon is oxidized to carbonic acid (CO_2), for this is out of the question. The reactions are internal and take place in the metal itself or within the covering of slag, and under these conditions carbonic oxide only can be formed. This may be subsequently burned in the furnace or regenerators, but while such combustion may decrease temporarily the amount of fuel consumed, it can have no influence on the immediate heat history of the metal.

If, however, we do assume the untenable proposition that the carbon is burned to carbonic acid (CO_2), then calculation shows that things are worse than before, for 333.4 kilos of ore must be added to supply the increased amount of oxygen needed by the carbon, instead of 166.7 kilos, as shown before, and this more than makes up for the extra heat produced. Under this assumption the figures for carbon are as follows:

	Calories.
Heat absorbed by reducing ore.....	407,516
Heat created in burning to CO_2.....	304,988
Net heat absorbed.....	102,528

Thus the reaction between oxide of iron and pig-iron in an open-hearth furnace, even when the oxide is in a fluid state, does

not heat the bath, but cools it, and as the flame is the only heating agent, the more rapid the reaction the lower will be the resultant temperature of the bath. The absorption of heat by the reduction of ore may be illustrated in a Bessemer converter. The addition of four hundred pounds of ore at the beginning of the blow will have as much cooling effect as one thousand pounds of scrap. It is hardly likely that the fusion of the ore takes so much more heat than the fusion of steel, and the oxygen should be a source of heat, as it assists in burning the silicon more quickly and renders unnecessary the admission of a great volume of nitrogen that would enter if air had to be supplied. We are driven to the conclusion that the cooling effect is due to the absorption of energy in the separation of iron from its oxygen. The union of this oxygen with silicon should be a source of heat, but if the silicon is present, it would be burned anyway by the blast whether the ore is added or not, and therefore the heat produced by it will be the same in either case, save a certain gain from the absence of nitrogen.

SEC. XIIf.—*Ore needed to reduce a bath of pig-iron.*—In the last section it was found that for every ton of pig-iron 500 pounds of ore are needed to oxidize the silicon and carbon, and of this amount 80 pounds will be used in supplying the oxide of iron for the slag. This calculation assumed that the ore was pure Fe_2O_3, which is never true, and did not allow for the presence of silica from other sources. Every pound of silica in the charge will claim a certain amount of FeO in order to form a slag, and this calls for an increased amount of ore. It was also assumed that the pig-iron contained one per cent. silicon, and it is necessary to change the figures if there is a different content of this element. No allowance was made for the action of the flame, as the last section was devoted exclusively to the heat generated or absorbed by an internal reaction. It may be well, therefore, to see how theoretical calculations agree with practical results.

In Section XIIb were given some data on the use of pig-iron in basic furnaces at Steelton. It was shown that in charging 544,430 pounds of pig-iron, most of it being cold, the ore used amounted to 144,100 pounds, or 593 pounds per ton, while with liquid metal the ore was 643 pounds per ton. This is more than was found by the previous calculation, but there are two things to be taken into consideration: (1) the action of the flame, (2) the

fact that the metal contained 1.4 per cent. silicon and 0.6 per cent. manganese. Table XII-G shows the amount of oxygen needed for the charges in Section XIIb.

TABLE XII-G.

Oxygen Needed for Pig-Iron Charges.

	Cold Pig Pounds.	Direct Metal. Pounds.
Pig iron	544 430	405.287
Silicon 1.4 per cent	7,622	5 674
Carbon 3.75 per cent	20,415	15,198
Manganese 0.6 per cent	3,267	2,432
Fe in slag	44,270	34.130
Oxygen for silicon	8.710	6.485
Oxygen for carbon	27,220	20,264
Oxygen for manganese	950	707
Oxygen for Fe in slag	12 650	9,751
Total oxygen needed	49,530	37,207
Fe_2O_3 needed	165,100	124,020
Ore needed (94 per cent.)	175.640	131 940
Ore used	144.100	116,300

With cold pig-iron, the ore was 82.0 per cent. of what was theoretically necessary, while with liquid metal it was 88.1 per cent. A charge of cold pig-iron should use less ore, as part of the oxidation is done by the flame. The difference will be even greater than is shown, as the series called "cold pig" was really composed of nearly 30 per cent. of molten metal. Thus in the case of the liquid metal, the amount of ore called for by theory agrees within 12 per cent. of the amount used. I have found a similar agreement in the results of the eighty heats mentioned in the discussion of the Bertrand Thiel process. The average heat contained 27,140 pounds of pig-iron, nearly all charged in a molten state. The average amount of ore was 7466 pounds, or 616 pounds to the ton. The pig-iron at Kladno was of the following composition in per cent.:

C 3.5 P 1.5 Si 1.0 Mn 0.4

Such an iron will demand 24 per cent. more oxygen than an iron containing 1.0 per cent. Si, 3.75 per cent. C, and 0.6 per cent. Mn, and in the Bertrand Thiel process much oxygen is supplied by the flame as it fuses the scrap in the secondary furnace, while some

oxygen is furnished by the limestone. I find also a close agreement in the records published by Mr. Talbot. The six heats given by him are not consecutive, but the composition of the metal before the first addition of pig-iron and after the last addition were similar, as shown by the following averages:

	C.	P.	Mn.
First metal	.06	.030	.10
Last metal	.13	.035	.15

It would seem fair, therefore, to add together the amounts of pig-iron and ore for the six heats, and to average the figures showing the chemical composition. The results are given in Table XII-H, all estimated figures being in parentheses:

TABLE XII-H.

Oxygen used in the Talbot Furnace.

Total pig iron in six heats..... 212,100 pounds.
Average composition..... { C 3.75 P 0.85 / Mn 0.60 Si 0.58

Additions.	Pounds.	Per cent. metallic iron.	Pounds free oxygen.
Scale	22,400	74 5	4.768
Ore	15,100	58.0	3 754
Cinder	13,800	66.8	2,634
Manganese ore	2.500	(20.0)	620
Limestone	23,240	.....	2,70^
Total	.....	.....	14,476

The ore and limestone account for 14,476 pounds of oxygen. This assumes that the carbonic acid of the limestone is broken up when in contact with melted pig-iron and that one atom of oxygen is set free. The amount of silica present is shown in Table XII-I. The average of the slags showed 12.75 per cent. SiO_2 and 15.13 per cent. Fe=19.45 per cent. FeO. According to this proportion, the presence of 4827 pounds of SiO_2 in the slag would call for 7364 pounds FeO=5728 pounds Fe, and 1636 pounds of oxygen would be held by this iron and not be available for oxidizing the metalloids. The calculation, therefore, shows that 14,476—1636=12,840 pounds of oxygen are available. The amount of oxygen required is shown in Table XII-J:

TABLE XII-I.

Silica in the Talbot Furnace.

		SiO_2 Per cent.	SiO_2 Pounds.
Scale	22,400	0.50	112
Ore	15,100	3.00	458
Cinder	13,800	8.00	1,104
Manganese ore	2,500	(8.00)	(200)
Limestone	23,240	(1.00)	(232)
From roof and walls (est.)	.....	.....	(50)
Dolomite additions (est.)	.....	.....	(40)
From oxidation of silicon	.....	.....	2,636
Total	.....	.....	4,827

Thus 14,708 pounds of oxygen are necessary to burn the metalloids, while 12,840 pounds of available oxygen have been added in the ore and limestone. This leaves 1868 pounds to be supplied by the flame.

The amount of oxygen theoretically necessary agrees closely with the amount added and available, the discrepancy being less than 13 per cent.; the figure given for Steelton agreed within 12 per cent.

TABLE XII-J.

Oxygen in the Talbot Furnace.

Element.	Per cent.	Pounds present.	Oxygen needed, pounds.
Si	0.56	1,230	1,406 = 2,636 lbs. SiO_2
C	3.75	7,954	10,605 = 18,559 lbs. CO
P	0.85	1,803	2,327 = 4,130 lbs. P_2O_5
Mn	0.60	1,273	370 = 1,643 lbs. MnO
	5.78	.....	14,708

In the case of the Bertrand Thiel process, the difference was about 16 per cent., but allowance was not made for the oxidizing effect of the limestone.

Thus these calculations are not all guesswork and often there can be found corroborative testimony. For instance, Mr. Talbot gives the composition of the final slags in the furnace at the end of five different weeks. The average shows 39.07 per cent. CaO, the minimum 37.65 per cent. and the maximum 40.69 per cent. The

additions of limestone were 23,240 pounds, giving 13,000 pounds of CaO, and if the slag contained 39.07 per cent. of CaO the weight of the slag would be 33,300 pounds. There were 4827 pounds of silica added and the slag was supposed to contain 12.75 per cent. of SiO_2. This calls for 37,860 pounds of slag, so that the weight of the slag found by these two different methods agrees within 12 per cent. On a different series of twenty-seven heats Mr. Talbot gives the weight of the slag, and if we calculate this so as to be in proportion to the weight of metal, the slag would weigh 42,000 pounds, when by our two theoretical calculations founded on other heats it would be 33,300 and 37,860 pounds. Variations in the pig-iron might account for greater discrepancies than these.

We may say with some certainty that in the pig-and-ore process, with molten pig-iron in a basic furnace, the oxidation of the metalloids is mainly due to the ore and very little to the flame. When pig-iron is charged cold there is more oxidation during melting, and the amount of ore will be reduced. When a mixture of pig and scrap is charged, the time of melting is lengthened and the stock is exposed longer to the flame and the oxidation done by the gases is greater.

SEC. XIIg.—*Gain in weight by reduction of ore.*—When iron ore is added to an open-hearth bath, the metalloids are oxidized and the iron is reduced. A certain amount of the oxide is lost in the slag, this amount varying with the amount and the nature of the slag. An open-hearth slag will usually carry about a certain percentage of iron, and the greater the quantity of slag the greater the loss of iron. Every pound of silicon in the pig-iron produces silica and increases the amount of lime necessary and increases the amount of iron that must accompany the resultant cinder. Every pound of silica in the ore and in the lime, and every pound from the erosion of the bottom or the melting of the roof, increases the volume of the slag and the loss of iron. Given the weight of silica present, together with the percentage of silica in the slag, and the weight of the slag may be found by simple division. A simpler way of making a rough estimate of the weight of a basic slag is to double the amount of burned lime used, or if limestone is added, the weight of the slag will be about 25 per cent. more than the weight of the stone, for limestone is a little over half CaO and burned lime is somewhat less than half CaO, owing to incomplete burning and

to moisture. Open-hearth slag contains from 35 to 45 per cent. of CaO and the proportions given will hold good for a rough calculation. The slag will also carry about 16 per cent. of iron, so that it is easy to find what is carried away in the cinder. For special investigation it is necessary to have actual weights and chemical analyses.

In Section XIIb there were given data on pig-and-ore practice at Steelton, where the gain in working cold pig was 3.1 per cent. and with liquid metal 4.95 per cent. It was also pointed out that the high content of silicon in the pig-iron caused a loss of iron in the slag and that with low silicon the loss would have been about 7 per cent. In a paper by Mr. Talbot* there are given data on the use of pig-iron with 0.58 per cent. of silicon. Two series of charges are shown, on one of which the weight of the slag is given. Table XII-K gives calculations on the amounts of metallic iron; all estimates are in parentheses. The weight of the slag in the second

TABLE XII-K.

Distribution of the Metallic Iron in the Talbot Furnace.

Additions, material.	Per cent. Iron.	First Series.		Second Series.	
		Total added.	Pounds Metallic Iron.	Total added.	Pounds Metallic Iron.
Liquid pig	.....	1,053,100	.....	1,045,900	.....
Cold pig	.....	31,150	.....	19,400	.....
Total pig	98.94	1,084,250	1,084,544	1,065,300	1,000,743
Scrap	99.25	22,750	22,579	42,300	41,980
Ferro	(12.00)	4,140	497	4,440	533
Silico	(75.00)	2,260	1,695	2,200	1,650
Ore	58.00	89,810	52,090	112,400	65,192
Cinder	66.80	70,150	46,860	40,000	26,720
Scale	74.50	91,100	67,795	77,600	57,812
Manganese ore	(20.00)	23,250	4,650	7,600	1,520
Total	.....	.....	1,214,710	.....	1,208,100
Ingots	.....	1,146,294	.....	1,130,950	.....
Scrap	.....	37,805	.....	50,500	.....
Total	99.25	1,184,099	1,175,218	1,181,450	1,172,589
Metallic iron not appearing as product	.....	.....	39,492	.....	30,511
Slag = (15.13) per cent. Fe.	.....	219,000	33,135	(215,200)	32,560
Iron unaccounted for	.....	.....	6.357	Excess by calculation.	2,049
Per cent. unaccounted for.	.....	.....	00.52	Per cent. excess	0.17

* *Journal I. and S. I.*, Vol. I, 1900.

series is calculated to give the same weight per ton of pig-iron as for the first series.

In the discussion of Mr. Talbot's paper, Mr. Monell gave figures of the work at Homestead, but the data were not complete and a calculation along the same lines as the foregoing leaves 5.4 per cent. of metallic iron unaccounted for. Mr. Hartshorne* gives a summary for the work at Kladno, but this also is incomplete and the figures indicate that 8.2 per cent. has disappeared. It is only by the most careful weighing that the records can be of value on this question of loss, for it is easy to make a mistake of one per cent. in weighing the stock or the ingots. The difference between a gain of 3 per cent. and 4 per cent. in an open-hearth furnace is a very important matter, but it is necessary to find out whether it is in the operation of the furnace or in keeping the accounts.

When the loss is found by subtracting the product from the stock used, it is as if we should determine the percentage of silicon in pig-iron by determining the phosphorus, manganese, sulphur, copper and metallic iron, and then subtracting their sum from one hundred and calling the remainder silicon. Every one recognizes the error involved in a "determination by difference." This method has its uses, and the determination is correct within certain limits, but it must not be accepted too implicitly. In important investigations the slag should be weighed and analyzed, and if the loss of metallic iron in the slag agrees with the iron not otherwise accounted for, there is a check on the whole calculation showing that the weights are right for both metal and slag. The results given by Mr. Talbot answer these conditions and are quoted here as corroborative of the experiments made at Steelton.

The whole matter of gain and loss in open-hearth practice is a question of terms. Usually the weight of the ore is not reckoned. Thus in a heat of all pig-iron there will be 50 tons of iron and 12 tons of ore, and if the ingots weigh 50 tons we say the loss is *nil*, disregarding the 12 tons of ore containing 7 tons of metallic iron. If, on the other hand, we add the weight of the ore, we are again wrong, for this ore contains 5 tons of oxygen, silica and water. If the actual content of metallic iron be calculated in the ore addition, then the percentage of water must be allowed for, and if this refinement be carried out, then we must subtract the carbon and

* *Trans. A. I. M. E.*, February, 1900.

silicon in the pig-iron, which will amount to 5 per cent. of the total. In the practical conduct of a steel plant these data are not necessary, but they become of value in the discussion of different methods. Thus Mr. Talbot refers to the gain in his process, and the fact may escape notice that a large part of the oxide additions is scale containing 74.5 per cent. of metallic iron. In the case of a 50-ton charge using 12 tons of ordinary ore, carrying 62 per cent. of iron, in the wet state, the metallic iron in this addition will be 7.44 tons. If the same quantity of rich scale be used, the amount of iron will be 8.94 tons, a difference of 1.50 tons of metallic iron in a charge of 50 tons, or 3 per cent. of the weight of ingots. Thus the use of rich scale instead of rich ore means a gain of 3 per cent. in the ingots, and there is no glory to be given to the process on account of it because it is inevitable. Scale was used to bring down a bath of pig-iron long before an open-hearth furnace was built. It has less oxidizing power per unit of iron than hematite ore, so that it is possible to use more than would be used of rich ore and the extra iron is clear gain.

SEC. XIIh.—*The duplex process.*—The use of all pig-iron in a stationary basic open-hearth furnace is not altogether advantageous, and it is an easy and attractive solution of the problem to first desiliconize and partially decarburize in a Bessemer converter, either acid or basic, and then finish in an open-hearth furnace, either acid or basic. At one works in Europe this practice has been carried on for some years, and the operation is an easy way of making steel from phosphoric pig-iron. I believe it is an expensive way, for more than one reason. In the acid converter, the loss will be very nearly as much as in the making of steel. The silicon will be entirely oxidized and the full quantity of slag formed. The slag will be somewhat more viscous if the charge is not entirely decarburized, but under these conditions the amount of shot will be more than when the slag is liquid. The total loss of iron, chemically combined and mechanically held, will be constant, whether the slag be viscous or liquid. The carbon must be reduced to about one per cent. if the open-hearth furnace is to do its work in quick time, and we have the following result:

Loss in the converter:

		Per cent.
Silicon		1.50
Carbon		3.00
Iron in slag.		
Combined	1.8	
Shot	0.7	2.50
Total		7.00

Calculation of increment in converter:

100 tons pig-iron	@ $11.00	$1100.00
93 tons metal cost		1100.00
1 ton metal		11.83
Increment		.83

Calculation of increment in open-hearth furnace:

40 tons metal	@ $11.83	$473.20
½ ton ore	@ 4.00	2.00
1/3 ton ferro	@ 60.00	20.00
39.12 tons steel (3% loss)		495.20
1 ton steel		12.66
Increment		.83

Synopsis:

Increment in converter	0.83
Increment in open-hearth	0.83
Total increment	1.66

The term "increment" denotes the item of cost caused by the oxidation of part of the metal, and this increment is the same whether much or little ore is used, as the gain in weight from reduction of iron balances the cost of the ore. Whatever changes are made in the figures, the increment in the converter must be nearly the same as in the manufacture of steel, with the exception of the recarburizer, and this is found in the cost sheets of the open-hearth furnace. With this item omitted, the increment in the duplex process will be the sum of the increments in the Bessemer and open-hearth processes.

It is necessary, therefore, that the duplex process should offer positive economies to offset the higher increment charge, and this it fails to do. The cost of running a Bessemer plant for this purpose will be almost exactly the same as for making soft steel. There is scarcely an item save that of molds which will not be the same as if the molten metal from the converter were to go to a rolling mill. But it does not go to a rolling mill; it goes to an open-hearth

furnace, must be heated, ored, treated like any other charge and will take half the time that would be given to an ordinary heat if allowance is made for the interval of making bottom and other delays, which will be a constant for any charge. We have then practically all the increment of the Bessemer except the recarburizer, and all the increment of the open hearth, including the recarburizer; we have the total working costs of the Bessemer except the molds, and at least half the working costs of the open hearth. The sum of these items will exceed the cost of making steel by either the Bessemer converter alone or the open hearth alone. Notwithstanding these arguments, there are places where this combined process is advisable. Thus in Alabama the ores and coke are both inferior, and it is difficult to make iron suitable for a basic open hearth in both silicon and sulphur. The duplex process answers this difficulty by permitting the blast furnace to run at a higher temperature and eliminate the sulphur without such stringent specifications concerning sulphur.

CHAPTER XIII.

SEGREGATION AND HOMOGENEITY.

SECTION XIIIa.—*Cause of segregation.*—Every liquid has a critical point in temperature below which it may not cool without freezing. This transformation takes place by the rearrangement of the molecules into crystals, and in this rearrangement there is a tendency for each crystal-forming substance, whether an element or a compound, to separate from any substance with which it may be mixed. This tendency will result in a perfect isolation when the substances have little affinity for each other and freeze at widely different temperatures. Under these circumstances, if the temperature be slowly lowered, the more easily frozen substances will almost completely crystallize out, leaving the more fusible in a liquid state. The completeness of the separation will be lessened by a hastening of the rate of cooling, or a greater similarity between the freezing points of the mixed substances. It will also depend upon the proportion of the ingredients, for it will be more difficult for a crystal to form when its constituent molecules must find their way out of a large mass of a foreign medium, and such a crystal after so forming will be more likely to contain a certain proportion of the associated substances. Under unfavorable circumstances, as when the rate of cooling is rapid, or when the substances have nearly the same freezing temperature, or when they have an affinity for each other, the differentiation may be so much interfered with that there is no appreciable separation of the components.

All these unfavorable conditions are present in the solidification of steel.

First, the temperature of a charge, when poured from a converter or a furnace, is seldom more than 50° C. above the point of incipient congelation.

Second, the absolute temperature is so high, when compared with everything with which it comes in contact, that conduction and radiation proceed with excessive rapidity.

Third, in the manufacture of ingots for plates, beams, angles, and other rolled or hammered structural material, the steel is cast in direct contact with a thick iron mold, and the absorption of heat from the outside of the liquid is so rapid that a solid envelope is instantly formed, while the conducting power of this envelope is so great that the heat is continually carried from the interior to the surface.

Fourth, the different substances that compose the steel have so many affinities for each other, and combine in so many ways, that it is a gratuitous hypothesis to assume the existence of a definite carbide, or sulphide, or phosphide of iron, or a carbide, sulphide, or phosphide of manganese.

No matter how high or how low the content of metalloids in the steel, there is always a tendency toward the separation of crystals lower in carbon, sulphur, and phosphorus than the average, so that it is logical to conclude that there is a tendency for pure iron to crystallize, but that this is prevented by the affinity it has for carbon, sulphur, phosphorus, silicon, manganese and copper. This affinity, in conjunction with the rapid cooling, prevents differentiation until a thick envelope has formed on the outside of the ingot to check the loss of heat. Moreover, the process of segregation is self-corrective to some extent, since with every step in the contamination of the interior liquid there is an increasing tendency to the formation of impure crystals.

The liquid center is not homogeneous, for, as the impurities are eliminated from the solidifying envelope, they form alloys or compounds which are more fusible and of lower specific gravity than the steel, so that they float on the surface of the interior lake. As the level of the metal sinks during solidification, this scum will be deposited on the walls of the pipe cavity, while the history will end by the solidification of a highly impure mass in the apex of the inverted cone. When there is only a small proportion of sulphur, or phosphorus, or carbon, their hold is so firm that the iron cannot tear itself away, but in larger proportion the affinity of the surplus is weaker. This will explain why the tendency to segregation increases with an increase in the content of metalloids. Manganese,

copper and nickel do not come into this class, for their chemical similarity to iron prevents their separation.

Under ordinary circumstances the purification is so slight that it reduces the content of impurities in any part of the ingot but little below the average, even though it may result in the serious contamination of the small region which is the last to solidify. This arises from the fact that the surplus is concentrated in a very small quantity of steel. Thus, if the ingot weighs 4000 pounds and contains 0.50 per cent. of carbon, the first 3900 pounds of steel which solidifies should contain 19.5 pounds of carbon, while the last 100 pounds should contain only 0.5 pound; but if there is a separation of two per cent. of the impurities during the chilling of the 3900 pounds, then this first portion will hold only 19.5—0.39= 19.11 pounds of carbon, a content of 0.49 per cent. The last 100 pounds will hold not only its fair proportion of 0.5 pound of carbon, but also the 0.39 pound rejected by the earlier solidifying part, and will therefore contain 0.89 per cent. of carbon. Thus a considerable degree of irregularity can be accounted for without assuming any attempt on the part of the metalloids to isolate themselves from the iron, but by supposing a regular separation of iron in obedience to the laws of crystallization.

In addition to this elimination of iron there is a definite process of separation and liquation on the part of the metalloids, which sometimes makes itself known in the formation of a very impure spot in the center of the mass. The exact circumstances under which this occurs to an excessive degree are not known. Slow cooling aids in the work, and the most marked cases are found in large masses of metal, but it is also true that both these conditions may exist without marked irregularity. The separation of the metalloids probably does not take place to any great extent until the external envelope of the ingot is of a considerable thickness, so that cooling is retarded. When it does occur, the compounds which are formed, being lighter than the mother metal, rise to the top, making the upper part of the ingot richer in metalloids than the normal. The lower part of the ingot will contain less than the average content of alloyed elements, since whatever excess is in the top must have been taken from the bottom.

For this reason the center of an ingot is not always homogeneous, but this irregularity is lessened in the subsequent working of the

steel, particularly if it is heated for a long time, as in the case of large ingots, and also if it undergoes two different heatings and coolings, as in the case of ingots rolled into slabs or blooms, and then reheated to be rolled into plates or angles. During each heating and rolling and cooling there must be a redistribution and equalization of carbon in obedience to the laws of cementation, and since the largest ingots are kept longest in the heating furnaces, it follows that this one condition of larger mass, which is favorable to segregation, is partially self-corrective.

The best-known paper on the irregularity of steel is by Pourcel,* but, unfortunately, it reads like an *ex parte* argument to prove that because some steels exhibit serious irregularities, therefore all steels have the same fault. I shall try to show that all steels do not exhibit excessive concentration of impurities, that the highly segregated portions of an ingot are often small isolated areas in the interior of the mass, and that by using a steel of low phosphorus it may be assumed that the finished material is practically uniform.

SEC. XIIIb.—*Segregation in steel castings.*—The most extreme instances of irregularity would be expected in large masses cast in sand, and cooled slowly. Pourcel states that in the pipe cavity of such a casting a cake of metal was discovered which was separate from the surrounding walls. The composition of this formation, together with that of the walls of the pipe cavity and of the mother metal, is given in Table XIII-A. It should be noted that the original metal contained a higher proportion of phosphorus than should be present in steel castings, so that the conditions were favorable to segregation.

TABLE XIII-A.

Extreme Segregation in Pipe Cavity.

Origin of test.	Composition; per cent.				
	C.	Si.	S.	P.	Mn.
Ladle test	.240	.336	.074	.089	.970
Wall of pipe cavity	.680	.326	.325	.318	1.490
Cake, two inches thick in pipe cavity	1.274	.410	.418	.758	1.080

As testimony in an opposite direction, I found no segregation in a steel roll made by The Pennsylvania Steel Company. This was

* *Segregation and its Consequences in Ingots of Steel and Iron. Trans. A. I. M. E.*, Vol. XXII. p. 105.

TABLE XIII-B.

Composition of a 20-inch Steel Roll, Cast in Sand.

Place from which sample was taken.	Composition; per cent.				
	C.	P.	Mn.	S.	Cu.
Two inches from outer surface	.42	.050	.46	.026	.12
Five inches from outer surface	.51	.058	.46	.029	.11
Seven inches from outer surface	.48	.064	.46	.026	.10
Nine inches from outer surface	.47	.058	.46	.028	.14

a cylinder 20 inches in diameter, with a length of 31 feet. A piece four feet long was cut from the top, this amount having been added for a sink-head, and samples were taken at different depths from the outside to the central axis. There were no signs of piping at this point, so that the conditions are not similar to those cited from Pourcel, but as the general practice is to remove all the honeycombed portion of such a casting, the investigation is in the line of practical work. The results are given in Table XIII-B.

TABLE XIII-C.

Segregation in Plate Ingots.

Thickness of ingot in inches.	Part of ingot from which sample was taken.	Composition; per cent.		
		Carbon, by combustion.	Phosphorus.	Sulphur.
10	Preliminary test	und.	.053	.030
	Center, 6 inches from top	.187	.075	.035
	Center, 12 inches from top	.150	.057	.054
	Center, 18 inches from top	.179	.057	.054
	Center, 24 inches from top	.188	.062	.049
	Center, 8 inches from bottom	.145	.058	.044
10	Preliminary test	und.	.064	.051
	Center, 3 inches from top	.247	.061	.044
	Center, 6 inches from top	.264	.068	.097
	Center, 9 inches from top	.240	.078	.069
	Center, 12 inches from top	.295	.078	.069
	Center, 18 inches from top	.272	.081	.064
	Center, 8 inches from bottom	.275	.070	.057
10	Outside, 3 inches from top	.135	.007	.018
	Center, 3 inches from top	.278	.007	.020
	Center, 6 inches from top	.212	.008	.024
	Center, 12 inches from top	.205	.008	.024
	Center, 18 inches from top	.199	.008	.029
	Center, 8 inches from bottom	.159	.007	.017
	Outside, 8 inches from bottom	.164	.007	.020
10	Outside, 3 inches from top	.100	.054	.035
	Center, 3 inches from top	.230	.096	.067
	Center, 6 inches from top	.199	.084	.060
	Center, 9 inches from top	.213	.090	.068
	Center, 12 inches from top	.206	.090	.071
	Center, 8 inches from bottom	.184	.066	.042
	Outside, 8 inches from bottom	.186	.065	.031

SEC. XIIIc.—*Segregation in ingots cast in iron molds.*—Under the old system of plate manufacture, still carried out in some American works, an ingot is rolled into a plate at one heat, and

TABLE XIII-D.

Segregation in Large Ingots.

The ingots were rolled into a slab, and this was drilled on the center line. Test A is taken just below the top crop end; B is taken one-third WAY down the ingot, and C from the bottom of the ingot. The carbon in all ingots was between .15 and .25 per cent.

Heat number.	Size of ingot: inches.	Thickness of slab; in.	Origin of test	Depth at which drillings were taken; in.	Composition; per cent. P.	S.	Mn.	Cu.	Depth at which drillings were taken; in.	Composition; per cent. P.	S.	Mn.	Cu.	Depth at which drillings were taken; in.	Composition; per cent. P.	S.	Mn.	Cu.
8188	32×88	5	A	1	.027	.017	.52	und.	2	.041	.026	.77	und.	8	.020	.017	.53	und.
8192	32×88	7	A	1	.019	.021	.56	und.	2	.018	.019	.55	und.	8	.018	.021	.60	und.
10087	32×88	6½	A	1	.058	.087	.77	und.	2	.059	.087	.77	und.	8¼	.000	.040	.85	und.
8801	32×88	6	A	½	.038	.029	.49	und.	1½	.034	.036	.49	und.	2½	.034	.062	.49	und.
			B	½	.037	.038	.49	und.	1½	.038	.038	.48	und.	2½	.046	.047	.49	und.
8802	32×88	6	A	½	.030	.022	.43	und.	1½	.038	.022	.43	und.	2½	.031	.023	.43	und.
			B	½	.030	.028	.43	und.	1½	.038	.026	.42	und.	2½	.040	.026	.43	und.
9394	32×24	10	A	1	.011	.026	.48	.18	3	.015	.036	.50	.14	5	.017	.049	.51	.14
			B	1	.014	.037	.50	.18	3	.014	.038	.51	.14	5	.016	.043	.50	.14
			C	1	.014	.030	.48	.18	3	.013	.033	.48	.12	5	.013	.030	.47	.14
9681	32×24	7	A	1	.010	.021	.42	.10	3	.010	.021	.45	.09	8½	.013	.026	.44	.08
			B	1	.009	.019	.47	.10	3	.010	.020	.43	.09	8½	.013	.023	.43	.10
			C	1	.009	.020	.43	.09	3	.000	.023	.43	.09	8½	.000	.024	.45	.09
9471	32×24	8	A	1	.020	.020	.57	.04	3	.003	.035	.56	.04	4	.007	.030	.59	.05
			B	1	.024	.025	.58	.05	3	.024	.024	.43	.03	4	.024	.024	.50	.04
			C	1	.026	.023	.56	.05	3	.027	.024	.39	.04	4	.026	.023	.38	.05
8478	32×24	7	A	....	.010	.021	.59	.10	2½	.014	.024	.58	.13	8½	.011	.021	.59	.11
			B	....	.013	.023	.57	.13	2½	.013	.026	.58	.13	8½	.017	.043	.58	.11
			C	....	.013	.020	.57	.13	2½	.013	.026	.40	.11	8½	.013	.024	.38	.13
8479	32×24	6	A	....	.018	.022	.55	.11	2	.024	.035	.49	.12	8	.003	.040	.34	.12
			B	....	.019	.023	.56	.12	2	.030	.027	.55	.11	8	.020	.023	.56	.11
			C	....	.015	.020	.56	.10	2	.027	.031	.56	.10	8	.023	.020	.48	.10

when the sheets are of large size, each ingot gives just one plate. It is of importance to find whether such ingots are uniform through-

out, and Table XIII-C gives investigations made under my supervision.

Under another system of plate rolling, practiced at the larger American mills, and extensively abroad, it is the practice to make larger ingots which are rolled into slabs, these being reheated for the plate train. It would be supposed that these slabs would show greater segregation than is found in plate ingots, but this assumption is hardly sustained by Table XIII-D, which gives the results obtained by drilling into the axial line of slabs rolled from large ingots, made by The Pennsylvania Steel Co. The points below the top crop end, and one-third way down the ingot, include the most contaminated region. The concentration in these cases probably marks the extent of the action of simple crystallization, while more extreme cases would represent the liquation of fusible impure compounds.

SEC. XIIId.—*Homogeneity in plates.*—The fact that plates are not homogeneous when rolled from ordinary ingots does not become evident under ordinary inspection, since, generally, only one test-piece is taken from the sheet, and this comes from the edge, but it will be shown by Table XIII-E that the variations are by no means unimportant. The first instance is from Pourcel,* the next three from Cunningham,† while the last two are from my own investigations. The data on heat 11,393 were obtained by rolling an ingot on a universal mill into a long plate. The upper third of this plate was sheared into 16-inch lengths, and tests taken along the center line and the edge. A strip was also cut from the bottom end of the plate in the center and on the edge. The tests of heat 10,768 were from a "pitted" plate. The flaws in the bars render worthless any records of elongation, but the chemical results are valuable, while the determinations of tensile strength are approximately correct. The ingot was rolled on a shear mill to a thickness of three-quarter inch. The plate was only 112 inches long after trimming, so that the seven tests represent the entire length of the sheet.

A great deal of this irregularity between different parts of the same plate may be avoided by rolling from a slab. It would be untrue to say that segregation can be avoided by making a larger

* *Loc. cit.* † *Trans. A. I. M. E.*, XXIII, p. 626, *et seq.*

ingot, or that it can be counteracted by a greater amount of work upon the steel, but a slab will usually give a more uniform plate.

TABLE XIII-E.

Plates from Ordinary Plate Ingots.

Heat No.	Part of ingot corresponding to the place from which test was taken.	Ultimate strength; lbs. per sq. inch.	Elong. in 8 inches; per cent.	Reduction of area; per cent.	Composition; per cent. C.	P.	S.	Authority.
Not given.	Top, edge	65426	32.0	....	.24	.050	.025	Pourcel.
	Top, center	66848	27.0	....	.32	.100	.061	
	Bottom, edge	59636	33.0	....	.25	.060	.028	
	Bottom, center	59610	32.5	....	.25	.060	.022	
Not given.	Top, edge	58600	30.7	55.9	.15	.021	...	C'nningham.
	Top, center	58000	32.0	58.6	.17	.023	...	
	Middle, edge	59000	28.2	58.7	.15	.018	...	
	Middle, center	55900	28.5	55.0	.16	.022	...	
	Bottom, edge	55800	31.5	57.9	.16	.019	...	
	Bottom, center	60200	24.5	48.1	.16	.024	...	
Not given.	Top, edge	75900	9.5	....	.22	.064	...	C'nningham.
	Second piece, edge	69700	20.0	....	.20	.056	...	
	Third piece, edge	64200	25.0	....	.18	.084	...	
	Fourth piece, edge	65700	25.0	....	.19	.043	...	
	Fifth piece, edge	65000	27.0	....	.21	.066	...	
	Sixth piece, edge	63700	25.5	....	.19	.088	...	
	Seventh piece, edge	66600	23.8	....	.20	.089	...	
	Eighth piece, edge	61400	26.0	....	.17	.080	...	
	Ninth piece, edge	66600	24.0	....	.19	.040	...	
	Bottom	64600	23.8	....	.19	.040	...	
Not given.	Edge	59200	22.5	60.8	.08	.077	.040	C'nningham.
	4 inches from edge	66600	24.5	59.1	.08	.151	.068	
	8 inches from edge	67100	23.0	54.7	.09	.141	.085	
	Center	66500	20.0	52.0	.09	.158	.085	
11868	Preliminary test	56000	....	....	..	.077	.045	Author.
	Top, edge	61600	23.75	45.9	..	.128	.078	
	Top, center	65420	25.00	44.6	..	.097	.062	
	Second test, edge	63860	27.00	45.8	..	.110	.068	
	Second test, center	61490	27.00	44.8	..	.107	.063	
	Third test, edge	62020	25.25	38.6	..	.110	.068	
	Third test, center	60830	23.50	53.7	..	.109	.064	
	Fourth test, edge	59960	26.50	45.8	..	.098	.056	
	Fourth test, center	60460	29.50	52.5	..	.098	.045	
	Fifth test, edge	59940	28.50	49.9	..	.098	.056	
	Fifth test, center	59160	27.50	52.0	..	.096	.057	
	Sixth test; ⅓ way from top of ingot, edge	59620	27.00	47.5	..	.097	.055	
	Sixth test; ⅓ way from top of ingot, center	59920	23.75	51.2	..	.097	.042	
	Bottom, edge	54660	24.75	66.4	..	.078	.033	
	Bottom, center	58850	29.00	61.0	..	.070	.051	
10768	Preliminary test	65600	....	....	..	.059	.049	Author.
	Top, edge	62180	....	....	..	.088	.057	
	Top, center	63840	....	....	..	.095	.058	
	Second test, edge	61140	....	....	..	.075	.043	
	Second test, center	62900	....	....	..	.083	.045	
	Third test, edge	56090	....	....	..	.051	.031	
	Third test, center	61280	....	....	..	.081	.045	
	Fourth test, edge	63480	....	....	..	.051	.033	
	Fourth test, center	60620	....	....	..	.084	.050	
	Fifth test, edge	58400	....	....	..	.051	.032	
	Fifth test, center	61420	....	....	..	.000	.051	
	Sixth test, edge	56920	....	....	..	.062	.036	
	Sixth test, center	61000	....	....	..	.080	.043	
	Bottom, edge	56220	....	....	..	.055	.042	
	Bottom, center	60230	....	....	..	.075	.038	

This will be shown by Table XIII-F, which gives the results obtained by testing the edge and the middle of universal-mill plates which were made from slabs from the same ingot. A record was kept of the position of each slab, and the tests were from the top end of each plate. The list gives the same information as if the whole ingot had been rolled into one plate and cut up for testing. The segregation in the central axis is shown by a slightly higher content of metalloids, and a higher tensile strength, but the variations between parts of the same plate, and the variations between different plates, are less than shown in Table XIII-E for plates rolled directly from ingots.

The usual way of testing is to take a strip from a corner of the

TABLE XIII-F.

Universal Mill Plates, Rolled from Slabs.

NOTE.—Plate No. 1 represents the bottom of the ingot, the others being numbered consecutively toward the top.

Heat No.	No. of plate.	Part of plate.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Composition; per cent.		
							P.	S	Mn.
2905 Acid.	1	Edge,	33080	54040	29.50	59.1	056	.040	.39
		Middle,	35880	55000	27.50	61.8	.074	.040	.38
	2	Edge,	33240	54000	29.50	63 8	.068	044	.36
		Middle,	34870	55540	29.00	61.3	.074	039	.37
	3	Edge,	32570	53220	31 00	62.5	.068	.040	.37
		Middle,	34070	55420	30.50	62 1	.074	040	.36
	4	Edge,	33430	53400	31.25	60.6	.054	·040	.37
		Middle,	35240	56450	30.50	58.4	.074	.045	.35
	5	Edge,	33270	54080	30 75	60.7	.080	.047	.36
		Middle,	34660	56840	28.00	57.1	.088	052	.35
	6	Edge,	33520	54280	31.00	57.8	.077	.05(	.37
		Middle,	35000	57280	29.25	56.7	087	.048	.38
	7	Edge,	33150	54120	29 25	59.5	.071	.046	.36
		Middle,	35110	56180	26 25	56.2	.088	060	.36
9765 Basic.	1	Edge,	34050	55360	29.50	63.2	.007	.038	.45
		Middle,	31900	54440	31.50	64.2	.007	.032	.43
	2	Edge,	33580	55950	30.50	59 2	.008	.045	.45
		Middle,	32460	58780	31.75	63.6	.007	.031	.43
	3	Edge,	33210	56340	28 75	57.8	.007	.040	.45
		Middle,	33170	55240	32.50	63.1	008	.035	.43
	4	Edge,	33590	56580	30.50	56.5	.007	.036	.45
		Middle,	32550	56020	30.25	60.4	.008	036	.43
	5	Edge,	33560	56340	28.75	58.2	007	.042	.46
		Middle,	32800	57240	30.00	58 6	.008	.040	.44

plate, and Table XIII-G gives the records so obtained from one-quarter-inch sheets, rolled from basic open-hearth slabs made by The Pennsylvania Steel Company. The ingots from which the slabs were made varied in section from 26"x24" to 38"x32", and weighed from 6 to 10 tons each. A record was kept of the part of the ingot from which each slab came, and the corresponding plates were tested both in the natural and in the annealed states. The table gives only the results on annealed bars, for by the reheating and cooling the artificial effects of cold finishing were avoided, and all test-pieces were brought to a common ground of comparison. The plates of any one heat are all of one thickness, the discard of other sizes accounting for the missing members. In each case the order in the list follows the order in the ingot from top to bottom, and the plates from the top give a slightly higher strength than those from the bottom, but the variations are unimportant, not being as great as will often be found in different parts of a single plate rolled from an ordinary plate ingot.

The carbon determinations in Table XIII-G are inaccurate, since

TABLE XIII-G.

Annealed Bars from Plates Rolled from Basic Slabs.

NOTE.—Carbon was determined by color and is therefore unreliable.

Heat number.	Thickness of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
55ER. 20-ton heat.	All ¼ inch.	1st ingot.	Top,	49080	31830	26.75	65.2	.11	.015	.31	.027
				48330	31170	32.00	63.6	.15	.018	.32	.020
				47750	29980	34.50	67.0	.16	.015	.32	.022
				48500	31760	29.50	66.3	.13	.018	.31	.023
				47810	31110	33.00	68.1	.12	.015	.31	.023
				46970	30090	35.00	64.5	.12	.015	.31	.019
			Bottom,	48200	31000	32.50	64.3	.11	.017	.31	.025
			Average,	48091	31077	33.32	65.6	.13	.015	.31	.023
		2d ingot.	Top,	49380	32080	33.00	64.2	.10	.016	.31	.025
				48010	28760	33.00	65.7	.16	.018	.35	.023
				48760	32080	33.75	64.9	.13	.018	.31	.026
				49170	32010	32.00	64.2	.13	.015	.32	.024
				49040	29940	31.75	60.7	.12	.014	.31	.025
				47670	30090	33.00	63.8	.14	.013	.34	.019
			Bottom,	46960	31280	33.50	65.3	.11	.013	.32	.021
			Average,	48418	30899	32.71	64.1	.13	.015	.32	.023

TABLE XIII-G.—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
8663. 20-ton heat.	All ¼ inch.	1st ingot.	Top,	51040	32710	31.00	63.8	.13	.014	.48	.014
				51660	33060	30.50	64.1	.12	.014	.46	.021
				51620	33180	33.00	62.8	.13	.018	.42	.025
				51760	32280	32.50	63.5	.14	.011	.44	.024
				51200	31730	31.50	61.1	.13	.017	.41	.024
				50470	32310	32.75	61.8	.12	.006	.45	.023
				50260	33340	32.50	62.6	.10	.012	.45	.020
			Bottom,	50830	32220	33.00	62.1	.10	.016	.47	.021
			Average,	51104	32488	32.09	62.7	.12	.014	.45	.022
		2d ingot.	Top,	52160	32450	32.00	57.0	.14	.009	.45	.025
				52050	31330	32.00	60.7	.12	.017	.46	.024
				52240	32940	33.00	62.6	.11	.018	.47	.023
				50600	33020	31.00	61.0	.11	.013	.46	.016
				50820	32240	32.25	61.2	.12	.014	.44	.022
				50360	32470	32.50	63.5	.13	.005	.45	.022
				50530	32240	32.75	60.0	.12	.013	.46	.016
			Bottom,	49980	31850	34.50	62.8	.11	.012	.46	.016
			Average,	51080	32318	32.50	61.1	.12	.013	.46	.021
8627. 80-ton heat.	All ¼ inch.	1st ingot.	Top,	53620	32860	31.00	60.2	.16	.019	.44	.032
				52210	36130	32.50	65.0	.16	.019	.43	.032
				50940	31730	32.00	65.7	.14	.016	.44	.028
				50860	30590	28.75	60.0	.15	.019	.44	.029
			Bottom,	50000	31840	31.50	56.4	.14	.016	.44	.025
			Average,	51296	32640	31.15	61.5	.15	.018	.44	.029
		2d ingot.	Top,	51880	30380	32.50	65.5	.14	.017	.42	.029
				53060	30660	28.75	55.2	.15	.024	.44	.038
				52820	35450	27.00	62.2	.16	.021	.44	.031
				52970	33540	31.25	58.9	.15	.017	.44	.030
				52870	31840	31.75	57.9	.15	.019	.44	.033
				50860	30070	32.50	61.4	.15	.019	.44	.029
				50000	28730	35.00	62.7	.14	.017	.44	.029
			Bottom,	50950	31280	35.50	64.5	.14	.016	.44	.025
			Average,	51926	32681	31.78	61.0	.15	.019	.44	.030
8626. 80-ton heat.	All ¼ inch.	1st ingot.	Top,	54160	36280	26.00	61.5	.13	.039	.32	.050
				53840	38210	27.25	60.1	.13	.033	.28	.053
				54460	38070	23.25	61.4	.12	.035	.32	.050
				51200	35500	31.00	64.0	.13	.023	.28	.026
				53000	36370	30.50	60.9	.12	.031	.37	.051
				51740	37310	31.00	64.9	.11	.031	.31	.047
				52420	37200	27.50	65.2	.11	.030	.29	.046
			Bottom,	53020	37600	31.25	66.8	.12	.033	.29	.050
			Average,	52980	37561	29.09	63.0	.12	.033	.31	.043
		2d ingot.	Top,	54070	38520	27.50	64.4	.12	.036	.34	.053
				54180	38850	30.25	63.8	.13	.037	.31	.053
				51520	36090	26.00	65.6	.13	.036	.31	.057
				52520	36180	30.25	63.8	.11	.031	.31	.043
			Bottom,	52980	37770	31.00	66.0	.12	.031	.29	.044
			Average,	53044	37772	29.00	64.7	.12	.034	.31	.052
		3d ingot.	Top,	54850	37880	30.00	61.9	.13	.037	.26	.056
				54480	38560	28.75	63.8	.13	.035	.20	.043
				53960	38520	29.50	63.2	.12	.034	.22	.047
				53590	37800	28.75	63.8	.12	.033	.22	.045
			Bottom,	53130	37200	25.75	54.8	.12	.031	.23	.047
			Average,	54000	37906	28.55	61.4	.12	.034	.20	.049

TABLE XIII-G.—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
8332. 50-ton heat.	All ¼ inch.	1st ingot.	Top.	50270	36880	31.75	60.2	.12	.027	.35	.032
				51630	36510	32.00	64.0	.11	.023	.36	.027
				49180	35130	30.75	58.3	.11	.019	.37	.027
				50240	36090	29.25	59.2	.11	.024	.36	.030
			Bottom,	53520	36150	31.00	63.4	.13	.014	.43	.031
			Average,	50968	36152	30.95	61.0	.12	.021	.37	.029
		2d ingot.	Top,	53010	37080	27.50	61.1	.12	.027	.38	.039
				53020	39140	25.75	61.1	.13	.027	.38	.035
				51520	34270	25.50	58.0	.11	.021	.38	.032
				50400	37330	24.75	56.1	.12	.025	.40	.028
			Bottom,	52780	36810	23.50	56.0	.13	.023	.38	.031
			Average,	52256	36916	26.40	58.9	.12	.024	.37	.033
		3d ingot.	Top,	53610	36970	31.25	60.4	.13	.034	.38	.040
				51540	35700	27.00	61.5	.12	.030	.37	.033
				52760	36940	33.00	65.0	.11	.026	.37	.033
				52550	37040	32.00	62.3	.11	.023	.36	.023
			Bottom,	51490	40490	28.75	56.0	.11	.020	.39	.023
			Average,	52186	37426	30.40	61.0	.12	.028	.37	.033
8334. 50-ton heat.	All ¼ inch.	1st ingot.	Top,	56060	35890	30.00	60.0	.19	.025	.48	.030
				55580	34930	28.00	59.0	.14	.019	.46	.024
				54830	34450	31.25	62.0	.18	.019	.46	.023
				54280	35320	31.25	63.0	.14	.023	.46	.025
			Bottom,	54360	34400	30.50	62.2	.17	.023	.47	.021
			Average,	55024	34996	30.20	61.2	.15	.022	.47	.025
		2d ingot.	Top,	55680	35380	31.50	59.2	.11	.024	.49	.027
				55210	34580	29.50	62.3	.12	.024	.48	.027
				54120	35950	31.25	61.2	.14	.021	.47	.026
				53200	34460	31.25	62.7	.12	.020	.46	.020
			Bottom,	54180	34700	31.75	60.9	.13	.021	.49	.021
			Average,	54478	35014	31.05	61.3	.12	.022	.48	.024
		3d ingot.	Top,	54000	35440	31.50	62.3	.14	.020	.46	.021
				55120	36310	29.50	63.3	.13	.025	.48	.027
				54180	35060	30.75	62.9	.17	.024	.45	.023
				53940	34460	30.00	65.4	.14	.019	.46	.023
			Bottom,	53400	33590	31.25	63.6	.15	.019	.46	.020
			Average,	54128	34972	30.00	63.7	.15	.021	.46	.024
		4th ingot.	Top,	55120	34200	30.50	62.6	.16	.021	.47	.027
				54230	34940	29.50	61.9	.15	.024	.47	.025
				53960	35230	28.00	63.3	.13	.022	.54	.041
				52730	33400	32.50	63.3	.14	.021	.46	.024
			Bottom,	54730	34340	31.75	63.2	.14	.023	.46	.025
			Average,	54164	34442	30.45	63.0	.14	.022	.48	.028
		5th ingot.	Top,	56970	35710	30.25	65.3	.16	.023	.48	.024
				54640	34410	33.00	63.9	.16	.021	.47	.024
			Bottom,	53590	33210	32.00	64.9	.13	.019	.46	.021
			Average,	54067	34443	31.75	64.7	.15	.021	.47	.023
		6th ingot.	Top,	56550	35420	31.75	62.6	.15	.022	.48	.023
				54550	36180	32.00	64.6	.12	.021	.49	.026
			Bottom,	55560	37360	28.25	60.0	.15	.024	.49	.023
			Average,	54558	36330	30.67	63.4	.14	.022	.49	.024

TABLE XIII-G.—Continued.

Heat No.	Thick. of plate.		Part of ingot from which slab was cut.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per ct.	Chemical composition; per cent.			
								C.	P.	Mn.	S.
8265. 50-ton heat.	All ¼ inch.	1st ingot.	Top,	49980	29740	31.75	58.5	.11	.017	.32	.040
				49150	29680	33.00	63.5	.10	.017	.35	.041
			Bottom,	48190	30080	33.00	57.1	.11	.016	.36	.038
				48190	30270	30.25	60.8	.11	.016	.35	.043
			Average,	48858	29980	32.00	60.0	.11	.017	.32	.039
		2d ingot.	Top,	50480	28570	30.75	61.0	.13	.019	.33	.043
				49080	31880	33.75	62.6	.12	.018	.33	.036
				47740	29980	33.25	63.9	.10	.017	.33	.035
			Bottom,	48810	30480	33.00	64.7	.11	.019	.31	.036
			Average,	48890	30206	32.69	63.1	.12	.018	.33	.038
		3d ingot.	Top,	49680	30410	30.00	64.0	.11	.017	.36	.034
			Bottom,	48910	30510	30.50	63.0	.10	.017	.35	.036
			Average,	49270	30460	30.25	63.5	.10	.017	.36	.039
		4th ingot.	Top,	48440	30460	32.00	65.9	.10	.019	.32	.036
				47000	30530	34.00	67.2	.11	.017	.35	.036
			Bottom,	47260	29950	31.25	58.0	.13	.016	.35	.034
			Average,	47767	30280	32.42	60.4	.11	.017	.34	.035
8266. 50-ton heat.	All ¼ inch.	1st ingot.	Top,	50660	32710	35.00	64.7	.13	.017	.45	.022
				50860	30480	33.25	63.8	.13	.021	.44	.026
			Bottom,	53800	33710	29.25	58.6	.11	.025	.46	.037
			Average,	51798	32300	32.50	62.4	.12	.021	.45	.029
		2d ingot.	Top,	54080	33070	30.00	59.4	.15	.024	.46	.031
				52080	34100	31.25	63.9	.15	.022	.46	.029
				51520	32140	33.00	61.0	.12	.018	.44	.026
				50750	32340	33.25	64.2	.14	.020	.44	.023
			Bottom,	50280	31760	31.75	65.2	.13	.013	.43	.022
			Average,	51862	32902	31.85	62.7	.14	.019	.45	.026
		3d ingot.	Top,	53440	32440	32.50	60.7	.11	.024	.42	.030
				51020	33400	32.75	65.1	.13	.019	.42	.029
				50660	32650	31.25	61.9	.14	.021	.42	.027
			Bottom,	49260	31460	31.00	65.0	.15	.020	.41	.026
			Average,	51245	32488	31.88	63.2	.13	.021	.42	.028
		4th ingot.	Top,	52060	32460	31.75	64.2	.15	.028	.44	.030
				54260	34450	30.00	59.4	.17	.026	.44	.028
				52880	33450	29.50	62.8	.14	.024	.45	.030
			Bottom,	50890	32090	33.75	61.4	.10	.018	.42	.029
			Average,	52523	33113	31.25	62.0	.14	.024	.44	.029

they were made by the color method. The work was performed by men who are regularly engaged in doing nothing else, and without any attempt at extra care, but in order to see whether there really were any such differences in composition as the records would indicate, the samples showing the widest variations in three heats were reworked twice by color and once by combustion; the results

are given in Table XIII-H, and show that the variations in any one heat are in the third place from the decimal point.

TABLE XIII-H.

Variations in Carbon Content Due to Analytical Errors.

Group A is made up of pieces showing the highest carbons in the heat, and Group B of those showing the lowest.

Heat No.	Group.	Composition; per cent.					
		Original as given in Table XIII-G.			Reworked.		
		Carbon by color.	P.	Mn.	Duplicate determinations by color.		Average of group by combustion.
[illegible]	A	.15 .16	.018 .015	.81 .82	.13 .13	.14 .13	.113
	B	.11	.015	.81	.13	.14	.124
[illegible]	A	.19 .17 .17	.025 .022 .024	.48 .47 .45	.18 .17 .15	.19 .18 .16	.165
	B	.11 .12 .12	.024 .024 .020	.49 .48 .46	.17 .16 .16	.17 .16 .17	.158
[illegible]	A	.15 .17	.028 .026	.44 .44	.14 .14	.14 .15	.150
	B	.11 .10	.024 .018	.42 .42	.13 .14	.13 .14	.149

SEC. XIIIe.—*Acid rivet and angle steel.*—A good opportunity of investigating the homogeneity of a heat of steel occurs in the manufacture of rivet rods and angles, where tests may be taken from many different members. In the case of rivet rods, the test-pieces represent the entire cross-section of the ingot, and include the segregated portions. Table XIII-I gives records obtained from several tests taken at random from the rivet rods from five different heats, without any knowledge as to what part of the heat or what part of the ingot the tests came from. The natural bars are arranged in the order of tensile strength, while in parallel columns are the results obtained by annealing the same bar. Although all the pieces of one heat were annealed at the same time, and with care to have all conditions uniform, the variations in the strength of the treated bar are independent of the variations in the natural bar. This would indicate that the differences are due to irregularities in rolling and to determinative errors rather than to variations in the metal.

In further proof of this, drillings were taken from the three annealed bars of heat 10,168, which showed the highest tensile strength, and from the three which were weakest. The results are given in Table XIII-J.

The ingots from which these rods were made measured 16"x20" in cross-section and weighed about two tons each. In the case of angles, experiments were made at Steelton on ingots having a cross-section 24"x26" and weighing five tons. Blooms from several such ingots were stamped so as to denote from what part of the

TABLE XIII-I.

Rivet Rounds from Different Parts of the Same Heats.

All steels were made by The Pennsylvania Steel Co.

Heat No.	Kind of steel.	Weight of charge.	Diameter of bar.	Composition; per cent.	Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
					Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
10167.	Acid open-hearth.	110,000 pounds.	¾ inch.	C=.11; P=.068; S=.022; Mn=.34; Cu=and.	61200	55640	43960	34420	31.25	30.00	60.30	68.34
					60950	54760	42480	34840	33.00	29.50	62.73	65.91
					60800	52700	42790	33800	32.00	31.50	65.25	66.93
					60720	55180	43600	34700	31.25	32.50	64.76	67.57
					60210	54600	41160	34040	30.50	30.75	62.60	65.68
					60010	54960	41720	34040	30.50	32.50	64.76	67.74
					59970	54820	40770	33840	30.50	32.00	63.97	64.92
					59710	54340	40900	34320	32.50	32.50	63.43	63.78
					59620	54040	40920	34120	33.00	30.00	57.70	66.39
					59800	54600	40820	34080	34.50	33.00	65.96	66.05
	Average,				60260	54500	41860	34220	31.80	31.42	63.55	66.54
10162.	Acid open-hearth.	110,000 pounds.	⅝ inch.	C=.10; P=.011; S=.107; Mn=.40; Cu=.17.	56040	49990	37710	30200	33.25	34.75	65.73	66.70
					56000	50520	37800	30700	35.00	34.25	64.26	66.18
					55520	50520	37890	31750	31.50	35.75	61.86	66.94
					55420	51000	37360	31165	31.75	34.50	62.18	67.97
					55080	49460	36130	30910	33.00	34.75	56.06	66.70
					55040	51170	37980	31475	34.75	34.50	65.48	66.50
					54980	50400	37710	30665	33.00	35.50	59.64	66.68
					54950	50640	37800	31345	31.75	35.00	67.02	66.28
					54880	50520	37980	31970	33.00	35.00	64.09	66.04
					54720	50940	36880	31900	33.75	35.75	55.25	67.85
	Average,				55260	50520	37520	31210	33.07	34.97	62.15	66.86
10158.	Acid open-hearth.	110,000 pounds.	⅝ inch.	C=.09; P=.012; S=.021; Mn=.35; Cu=.12.	54000	48870	36280	30990	33.75	33.75	62.20	70.59
					53500	49460	35960	31220	34.50	36.25	63.32	66.57
					53400	48520	35710	31520	33.50	35.50	64.05	69.28
					52690	48290	35880	31190	33.75	32.50	66.49	68.77
					53300	48400	36060	31370	33.75	34.25	61.57	68.14
					52020	49760	35080	32710	33.75	36.25	63.27	67.52
					52020	48640	35080	30490	33.75	36.25	65.29	69.43
					52620	48520	35050	30590	31.25	35.00	62.04	69.49
					51910	49280	36280	32580	32.25	34.50	58.68	67.98
					51900	48410	34840	30650	33.75	33.75	63.72	66.95
	Average,				52980	48820	35700	31800	33.40	34.80	63.57	68.64

TABLE XIII-I.—Continued.

Heat No.	Kind of steel.	Weight of charge.	Diameter of bar.	Composition; per cent.	Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
					Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
10168.	Acid open-hearth.	110,000 pounds.	¼ inch.	C=.12; P=.013; S=.024; Mn=.39; Cu=.27.	55480	49460	37600	29870	32.50	28.75	67.45	65.30
					55480	49940	36670	30950	32.50	31.25	68.22	65.90
					55420	49460	38400	30110	33.25	31.75	68.40	67.70
					55400	49700	37250	31300	30.00	35.00	64.67	69.22
					55160	49700	37950	32780	30.00	32.50	64.97	69.23
					54770	50720	37600	31760	32.50	30.00	69.68	64.62
					54750	50420	38400	32740	33.75	33.75	63.15	61.12
					54690	50010	39120	33470	32.75	32.50	67.26	67.96
					54520	50660	38640	32220	33.00	31.25	67.17	67.25
					54220	49770	38900	32220	33.75	33.75	66.57	69.47
				Av'r'ge	54990	50006	38058	31578	32.40	32.05	66.76	66.72
			½ inch.	C=.12; P=.013; S=.024; Mn=.39; Cu=.27.	55000	50230	37710	31950	31.75	33.75	66.31	70.77
					54780	49170	37100	30810	33.75	35.00	62.88	68.77
					54700	50880	36750	31620	32.50	34.00	60.11	66.70
					54180	48920	37450	30840	31.75	35.00	62.30	68.77
					54170	48290	36980	30840	31.25	34.00	67.88	68.77
					53880	49080	36320	30780	31.00	36.00	60.20	68.43
					53770	50530	35610	31670	32.50	34.00	60.02	65.06
					53770	49060	35960	31120	32.75	35.50	65.73	69.76
					53800	50160	36700	31920	33.25	35.50	61.30	69.57
					53600	50640	35360	32400	33.00	35.00	66.49	68.63
				Average,	53970	49670	36450	31840	32.35	34.37	63.52	68.53
1520.	Basic open-hearth.	40,000 pounds.	½ inch.	C=.11; P=.02; S=.035; Mn=.51.	48340	. . . . .	33065	. . . . .	34.50	. . . .	71.37	. . . .
					47880	. . . . .	31580	. . . . .	35.00	. . . .	72.05	. . . .
					48450	. . . . .	33050	. . . . .	35.00	. . . .	72.05	. . . .
					48320	. . . . .	31600	. . . . .	37.00	. . . .	74.14	. . . .
					49175	. . . . .	33340	. . . . .	36.25	. . . .	70.09	. . . .
					48560	. . . . .	32760	. . . . .	33.75	. . . .	72.95	. . . .
					47780	. . . . .	33200	. . . . .	35.00	. . . .	74.49	. . . .
					48785	. . . . .	32180	. . . . .	34.00	. . . .	71.80	. . . .
					48340	. . . . .	32985	. . . . .	34.25	. . . .	71.92	. . . .
					48440	. . . . .	33270	. . . . .	34.00	. . . .	71.48	. . . .
					47885	. . . . .	32000	. . . . .	34.00	. . . .	72.72	. . . .
					48050	. . . . .	31920	. . . . .	33.75	. . . .	71.42	. . . .
					48860	. . . . .	32185	. . . . .	36.25	. . . .	74.28	. . . .
					48400	. . . . .	33880	. . . . .	33.75	. . . .	73.04	. . . .
				Average,	48384	. . . . .	32745	. . . . .	34.75	. . . .	72.49	. . . .

ingot each one came, and drillings were taken from the corresponding finished angles. The results are given in Table XIII-K, and show that each ingot was practically uniform. The drillings include the center of the bar, which is the most impure portion. In each case the first bloom in the list is the top of the ingot, and the last is the bottom; the varying number of blooms in the ingots arises from the different weight of the angles.

SEC. XIIIf.—*High-carbon steels.*—It would be expected that segregation would be most marked in ingots of high carbon, be-

TABLE XIII-J.

Rivet Rods from Heat 10,168, which showed the Greatest Differences in the Tensile Strength of the Annealed Bars.

Nature of Sample.	Ultimate strength; pounds per sq. inch.		Composition; per cent.			
	Natural.	Annealed.	C.	P.	S.	Mn.
Preliminary test	52280	. . . . .	.12	.013	.024	.39
Average of strongest three bars of ⅛ inch diameter . . .	53690	50690	.12	.013	.019	.30
Average of weakest three bars of ⅛ inch diameter . . .	54077	48680	.12	.013	.024	.30

cause such metal remains liquid for a long time, but even under these conditions separation of the impurities does not always occur. This will be shown by Tables XIII-L and XIII-M, which give the results of investigations by The Pennsylvania Steel Company. The data on carbon in Table XIII-L are of little importance, for a color determination is well-nigh worthless on high steels.

The determinations of carbon in Table XIII-M are made by combustion and are accurate, and they show a considerable variation in the distribution of this element; this might be expected when a large proportion is present, and its hold upon the iron correspondingly less firm. The sulphur and phosphorus are regular, the variations in the purer metal being almost within the limits of error. In the ingot of medium phosphorus, the percentage of variation is no more than in the others, but the actual range is greater. Although this would follow naturally, it is possible to show, by an incident which happened under my own observation, that concentration does not always occur, even in the case of impure steels.

A 50-ton acid open-hearth charge had been made containing .46 per cent. of carbon, together with unusually high manganese, phosphorus, and silicon. The ingots had a cross-section of 16"x20", and weighed 4000 pounds each. In loading them, one fell over and "bled" at the top. The amount of liquid metal thus lost did not exceed 25 pounds, although the cavity was completely emptied, so that if segregation existed to any considerable extent it should appear in this metal which remained liquid to the last. Table XIII-N will show that little segregation had taken place.

SEC. XIIIg.—*Acid open-hearth nickel steel.*—It is the impres-

sion among manufacturers of nickel steel that this element prevents segregation. In order to have some evidence upon this point, an investigation was conducted on an ingot of nickel steel made

TABLE XIII-K.

Composition of Angles, rolled from 26"x24" Ingots of Acid Steel.

NOTE.—The angle from the top of the ingot is marked No. 1, the next No. 2, and so on consecutively to the bottom.

Heat number.	No. of ingot.	No. of angle.	Composition; per cent.			No. of ingot.	No. of angle.	Composition; per cent.			No. of ingot.	No. of angle.	Composition; per cent.		
			S.	P.	Mn.			S.	P.	Mn.			S.	P.	Mn.
11891	A	1	.043	.008	.41	B	1	.023	.009	.41	D	1	.044	.000	.41
		2	.020	.006	.39		2	.039	.008	.39		2	.038	.004	.41
		3	.043	.003	.40		3	.046	.008	.40		3	.057	.056	.40
		4	.041	.001	.43		4	.046	.001	.43		4	.040	.003	.43
		5	.043	.001	.39		5	.051	.001	.43		5	.040	.000	.43
		6	.036	.001	.40		6	.035	.005	.43		6	.038	.003	.43
		7	.038	.000	.41		7	.038	.000	.43		7	.038	.008	.41
		8	.038	.006	.41										
	E	1	.053	.049	.41	F	1	.054	.076	.40	G	1	.039	.081	.38
		2	.039	.003	.40		2	.041	.003	.41		2	.039	.007	.40
		3	.039	.008	.40		3	.039	.029	.37		3	.039	.000	.38
		4	.039	.002	.41		4	.041	.028	.41		4	.037	.001	.38
		5	.039	.002	.41		5	.039	.028	.43		5	.036	.000	.38
		6	.041	.054	.41		6					6	.036	.006	.38
		7	.037	.000	.43							7	.038	.005	.41
10867	A	1	.053	.060		B	1	.054	.031		C	1	.051	.074	
		2	.049	.004			2	.041	.073			2	.043	.007	
		3	.044	.076			3	.040	.071			3	.041	.001	
		4	.053	.009			4	.041	.070			4	.040	.005	
		5	.040	.070			5	.040	.009			5	.040	.001	
		6	.038	.008			6	.042	.009			6	.038	.028	
		7	.038	.008			7	.040	.007			7	.040	.009	
		8	.043	.007			8	.043	.008			8	.043	.007	
		9	.038	.006			9	.036	.002			9	.036	.043	
		10	.039				10	.034	.003						
		11													

by The Pennsylvania Steel Company. The cross-section of the ingot was 18"x20", and the weight 5500 pounds. This was rolled into a piece 16 inches wide, 5 inches thick, and 20 feet long, and cut into five slabs. The top slab was rolled into a three-eighth-inch

TABLE XIII-L.

Distribution of Elements in a High-Carbon, Low-Phosphorus, Open-Hearth Ingot, 14 inches square, 63 inches long.

NOTE.—Made by The Pennsylvania Steel Company. Carbon was determined by color, and is, therefore, only approximate.

Part of the ingot from which test was taken.	Depth from which drillings were taken; in inches.	Composition; per cent.					
		C.	P.	Mn.	Average.		
					C.	P.	Mn.
Four inches from bottom,	2	.79	.013	.20	.77	.013	.20
	4	.78	.015	.20			
	6	.79	.013	.19			
	7	.72	.012	.19			
Fifteen inches from bottom,	2	.77	.011	.20	.81	.012	.20
	4	.87	.015	.20			
	6	.84	.011	.20			
	7	.78	.011	.19			
Twenty-six inches from bottom,	2	.80	.012	.18	.84	.012	.20
	4	.89	.014	.21			
	6	.85	.014	.21			
	7	.81	.009	.20			
Thirty-seven inches from bottom,	2	.77	.011	.20	.85	.013	.20
	4	.90	.014	.21			
	6	.89	.015	.20			
	7	.88	.012	.20			
Forty-eight inches from bottom; all above this would be cut off as scrap when the ingot is rolled,	2	.79	.011	.21	.88	.014	.20
	4	.91	.014	.20			
	6	.89	.016	.19			
	7	.94	.014	.21			
Four inches from top,	2	.74	.010	.21	.91	.016	.21
	4	.90	.016	.21			
	6	.95	.017	.21			
	7	1.06	.028	.21			

universal plate, the second slab into a three-eighth-inch sheared plate, the third slab into a half-inch universal plate, the fourth slab into a half-inch sheared plate, and the fifth slab was hammered into a bloom and rolled into 6″x4″ angles.

Each end of each slab was marked so as to note whether it was toward the top or bottom of the ingot, and the location of each test-piece in each plate was kept on record. Table XIII-O gives the results obtained from the different strips, while the diagram immediately below the table represents the entire length of the original piece produced by rolling the 18″x20″ ingot to a section of 16″x5″. The numbers on this diagram correspond to the numbers of the test-pieces in the table, and mark the place in the ingot from which the corresponding test-piece was derived.

There are evidences of segregation, both in a slightly higher tensile strength and in higher phosphorus and sulphur, in the center of the ingot near the top, but the differences are unimportant,

TABLE XIII-M.

Distribution of Elements in 7-inch Square Blooms Rolled from High-Carbon, Open-Hearth Ingots, 14 inches square.

A slice was cut crosswise from the rolled bloom at different places and drillings taken from the *center* of this slice, corresponding to the center of the ingot.

Kind of ingot.	Place from which slice was taken.	Composition; per cent.				
		C by comb.	P.	Mn	S.	Si.
Low-phosphorus ingot.	Ladle test	.984	.013	.09	.022	.12
	Top of ingot after cutting off 20 per cent. as scrap	.941	.015	.11	.012	.09
	One-fourth way down the ingot	.990	.019	.11	.010	.10
	One-half way down the ingot	.991	.017	.11	.012	.09
	Three-quarters way down the ingot	.982	.020	.11	.010	.11
	Bottom of ingot	1.012	.016	.11	.010	.11
Medium-phosphorus ingot.	Ladle test	1.440	.050	.28	.016	.12
	Top of ingot after cutting off 20 per cent. as scrap	1.205	.064	.28	.015	.16
	One-fourth way down the ingot	1.430	.059	.27	.015	.12
	One-half way down the ingot	1.443	.051	.27	.013	.12
	Three-quarters way down the ingot	1.400	.058	.27	.014	.12
	Bottom of ingot	1.450	.055	.27	.012	.12
Low-phosphorus ingot.	Ladle test	.913	.024	.18	.019	. .
	Top of ingot after cutting off 20 per cent. as scrap	.926	.021	.18	.018	. .
	One-fourth way down the ingot	.965	.022	.14	.018	. .
	One-half way down the ingot	.948	.021	.18	.020	. .
	Three-quarters way down the ingot	.956	.025	.18	.021	. .
	Bottom of ingot	.948	.021	.18	.021	. .

TABLE XIII-N.

Composition of the Liquid Interior of an Ingot.

Origin of sample.	Composition; per cent.				
	Carbon by combustion	P.	S.	Mn.	Si.
Metal from interior	.480	.095	.047	0.95	und.
Ladle test	.461	.091	.064	1.13	.12

and, as the carbon in the steel was .24 per cent., there seems to be good ground for the assumption that nickel prevents the separation of the metalloids. It has not prevented it altogether, however, and it is not probable that any other agent will ever be found competent for this task.

SEC. XIIIh.—*Investigations on Swedish steel.*—The experiments related in this chapter were, for the most part, made at Steelton; manufacturers, as a rule, do not want to discuss segregation at all, and published records are rare. Recently, however, an account has been written by Wahlberg* on investigations on

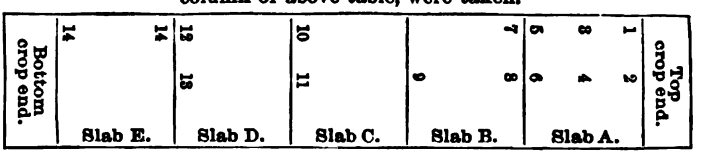
TABLE XIII-O.

Homogeneity of Acid Open-Hearth Nickel Steel.

Size of ingot, 18"x20"; made by The Pennsylvania Steel Company. Composition of preliminary test, per cent.: C, .24; Mn, .78; P, .032; S, .027.

Slab mark.	Shape into which slab was rolled.	No. of test.	Composition; per cent.				Ultimate strength; pounds per square inch.	Elastic limit; lbs. per square inch.	Elongation in 8 inches; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.
			Ni.	P.	Mn.	S.					
A	⅝-inch universal mill plate.	1	3.22	.033	0.78	.036	86480	59000	19.25	37.00	47.8
		2	3.21	.040	0.80	.046	88500	59500	20.50	36.00	39.1
		3	3.31	.035	0.78	.034	85140	59240	21.75	39.00	54.2
		4	3.24	.039	0.78	.036	88700	58100	19.75	34.50	38.6
		5	3.22	.031	0.77	.028	84080	57320	21.25	40.00	58.1
		6	3.29	.037	0.77	.026	85400	59410	19.75	38.00	51.5
B	⅝-inch sheared plate.	7	3.27	.035	0.77	.034	84440	58800	19.50	37.00	46.8
		8	3.29	.039	0.77	.037	86080	59640	17.00	31.50	42.8
		9	3.27	.037	0.78	.038	86520	59500	20.50	37.00	52.6
C	½-inch universal mill plate.	10	3.22	.037	0.77	.032	86200	58260	21.00	40.00	54.1
		11	3.22	.037	0.78	.032	85060	56760	22.00	42.00	58.1
D	½-inch sheared plate.	12	3.21	.035	0.77	.034	85180	56800	19.00	34.50	50.2
		13	3.21	.035	0.78	.033	84020	57600	20.50	39.00	52.2
E	Angles.	14	3.25	.038	0.77	.033	86960	58550	21.75	39.67	50.5

NOTE.—The following diagram shows the parts of the ingot which correspond to the places in the plates from which the tests, given in the third column of above table, were taken.



Swedish steels. He gives the determinations by three chemists of the carbon and phosphorus in different steels, and Table XIII-P shows the averages from his tables. Inspection will show that B, E, G, H, J and L, which is to say one-half of all the ingots, showed no segregation of either carbon or phosphorus. F, I and K showed segregation in the center of the top of both carbon and phosphorus, but none elsewhere. C and D showed segrega-

* *Journal I. and S. I.*, Vol II, 1901.

TABLE XIII-P.

Segregation in Swedish Ingots.

Calculated from Wahlberg: Journal I. and S. I.. Vol. II, 1901. Left-hand figures in each rectangle — surface at top and bottom. Right-hand figures = centre of ingot at top and bottom. Each figure is average of determinations by three chemists. Plain figures = carbon; parentheses in italics — phosphorus.

Top.	Top.	Top.
Surface. .096 (.025) .159 (.091) Center. A .095 (.031) .128 (.056)	Surface. .470 (.024) .475 (.029) Center. E .483 (.025) .469 (.025)	Surface. .929 (.035) 1.082 (.055) Center. I .975 (.043) .932 (.030)
Bottom.	Bottom.	Bottom.
Top.	Top.	Top.
Surface. .128 (.012) .129 (.015) Center. B .106 (.015) .115 (.015)	Surface. .508 (.033) .590 (.065) Center. F .495 (.034) .486 (.036)	Surface. 1.032 (.025) 906 (.021) Center. J .982 (.025) 1.024 (.027)
Bottom.	Bottom.	Bottom.
Top.	Top.	Top.
Surface. .125 (.020) .207 (.056) Center. C .117 (.019) .140 (.034)	Surface. .591 (.026) .594 (.031) Center. G .549 (.026) .543 (.025)	Surface. 1.055 (.025) 1.202 (.040) Center. K 1.102 (.026) 1.099 (.026)
Bottom.	Bottom.	Bottom.
Top	Top.	Top.
Surface. .220 (.028) .270 (.042) Center. D .192 (.023) .218 (.030)	Surface. .612 (.030) .675 (.034) Center. H .625 (.033) .631 (.034)	Surface. 1.234 (.028) 1.262 (.033) Center. L 1.240 (.031) 1.217 (.031)
Bottom.	Bottom.	Bottom.

tion in the top and a slight amount in the center of the bottom, while A showed marked segregation in the top and a considerable amount in the bottom of both carbon and phosphorus. It will be evident that by cutting off the top of the ingot the remainder of the steel will be practically uniform, for the central axis constitutes but a small portion of the finished material.

The burden of this chapter is to the effect that segregation is ever present; that the extent of the concentration bears a relation to the proportion of impurities present; that manganese, copper and nickel do not segregate to any extent, but that certain portions of the finished material will contain a higher percentage of carbon, phosphorus and sulphur than will be found in the tests cut from the edge of plates and bars, or than will be shown by the preliminary test. It is also indicated that a degree of uniformity, sufficient for practical needs, may be expected if the initial metal is low in phosphorus and sulphur.

CHAPTER XIV.

INFLUENCE OF HOT WORKING ON STEEL.

SECTION XIVa.—*Effect of thickness upon the physical properties.*—One of the fundamental difficulties in writing specifications is to decide the nature of the test-piece to be required, inasmuch as the strength and ductility will vary in pieces of different thickness, while the results will not be alike in tests cut from different structural shapes, like plates, angles and rounds, even though they be rolled from the same steel. From one point of view each piece of metal throughout a bridge should be of exactly the same strength per unit of section without regard to its thickness; but in taking this as a basis a serious trouble is encountered. Suppose, for instance, that a metal is required running between 56,000 and 64,000 pounds per square inch, and a charge is made which in three-eighth-inch plate gives 57,000 pounds. If this steel be rolled into seven-eighth-inch angles, or into one-inch plate, or into two-inch rounds, it is quite probable that these will run below the allowable minimum. On the other hand, if the steel gives 62,000 pounds in a preliminary test, the larger sections will give proper results, while one-quarter-inch plate will be too high in ultimate strength.

Where a structure is to be made of large quantities of very large or very small sections, it is well to specify that the test shall be made on the special thicknesses needed, but in ordinary cases it seems absurd to the practical mind that a heat of steel can be perfectly suitable for one size and unsuitable for another. It was the custom in the past for inspectors to recognize the situation and make tests from the usual sizes, with a full knowledge that thicker and thinner members would give different results, but in later practice there is a growing tendency to test each separate thickness, a change which has been the cause of great expense to the manufacturer. Provisions to cover this point should be incorporated into contracts and a certain definite allowance made for variations in the dimensions of the finished material. On the other hand the

requirements should be worded so that manufacturers would be obliged to put sufficient work on large members to render them of proper structure.

There is often a confusion of terms in considering the effect of work as represented by a large percentage of reduction from the ingot, and the effect of finishing at a low temperature. This is found most often in the case of plates, for it has been quite a general practice to roll these directly from the ingot in one heat. In order that a piece shall be finished hot enough under this practice, there has been a standing temptation to use a thin ingot; but, on the other hand, it has been almost universally shown that the best results are obtained when a large amount of work is put upon the piece during rolling.

SEC. XIVb.—*Discussion of Riley's investigations on the effect of work.*—The truth of this last statement was disputed by Riley,* who tabulated the results of testing different thicknesses of plate when rolled from ingots of varying section. In all cases the ingot was either hammered or cogged to a slab and this was reheated before finishing into a plate. His analysis of the records consisted in picking out individual cases and showing that the small ingots gave some results which were equal to those from the large ones, but this method of comparison must be recognized as entirely unworthy of the subject. It is true that the number of tests is very small, and it would not be surprising if the accidental variations in the double working should produce anomalous results; but even taking these very data and making comparisons by the proper system of averages, it will be found that they tell a story exactly opposite from the conclusions formulated by Mr. Riley. In Tables XIV-A and XIV-B such figures are presented.

In the comparison of the different thicknesses in Table XIV-A the thinner plates give much better results, the one-half-inch plate showing an increased ductility in spite of its greater strength. The one-quarter-inch plates are somewhat lower in elongation and two and one-half per cent. better in reduction of area than the one inch plates, but they possess 7600 pounds more strength, so that less ductility should be expected. This statement is open to criticism, as no account is taken of the effect of variation in the

* *Some Investigations as to the Effects of Different Methods of Treatment of Mild Steel in the Manufacture of Plates. Journal I. and S. I.*, Vol. I, 1887, 121.

dimensions of the test-piece, but Table XIV-B, which is free from this error, proves that the plates made from the large sizes have a higher tensile strength and greater ductility.

TABLE XIV-A.

Average Physical Results on Different Thicknesses of Steel Plates Without Regard to Size of Ingots; there being an Equal Number of Plates of each Thickness Rolled from Each Sized Ingot.*

Thickness of plate.	Ultimate strength; lbs. per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Annealed, ultimate strength; pounds per square inch.
One inch . . .	62087	24.40	40.20	59416
One-half inch.	64534	24.71	44.85	61018
One-quarter in.	69642	22.35	42.68	62989

TABLE XIV-B.

Average Physical Results on Plates from Different-Sized Ingots Without Regard to Thickness of Plate; there being the same Number of each Thickness Rolled from a Given Size.*

Size of ingot: in inches.	Thickness of slab in inches.	Ultimate strength; lbs. per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Annealed ultimate strength; pounds per square inch.
24x15	8	66155	24.14	45.79	62197
14x14	8	65296	23.91	44.13	62571
18x12	8	65128	23.77	41.38	60461
18x12	4	65520	23.68	40.00	60461
12x 6	4	64928	23.68	41.58	60013

Thus these experiments which were heralded as upsetting current beliefs are found to vindicate them; they do prove that in some cases very good results may be obtained by skillful manipulation under a bad system; but manufacturers have long since learned that a large amount of reduction is essential to secure reliable results in regular practice, and no short series of tests can upset this well-established fact.

SEC. XIVc.—*Amount of work necessary.*—Up to within a comparatively recent period it was a common practice in America to roll plates directly from the ingot in one heat. This was unsatisfactory for more than one reason. First, the rolling of thin plates involved either the making of small ingots, which was objectionable and costly, or it involved rolling them from a large ingot, which

* From data in *Journal I. and S. I.*, Vol. I., 1887, p. 121, *et seq.*

was very severe on the machinery; second, when the ingot was rolled into one single plate the segregated interior of the mass constituted a very considerable proportion of the finished piece, and it was generally out of the question to cut this part off, as by so doing a piece would be wasted which would be a very large proportion of the whole and which generally would be unsuited for other purposes on account of its dimensions.

Third, it is not possible to make every heat of steel just the exact composition and physical qualities desired, and if the steel be cast in ingots of a size suited for the making of certain plates, and if, on account of such variations in chemical or physical quality, they are not suited to the purpose for which they are made, they may be unsuited for any other purpose. On the other hand, when large ingots are cast and bloomed in a large mill and cut up into slabs, it is possible to know before the steel is rolled just what are the chemical and physical qualities of the metal, and the slabs may be made to suit the orders on hand. Moreover, the upper part of the ingot may be put into the less important work, while the bottom portion may be used for fire box plates and for other purposes calling for the best material. For these reasons the use of a slabbing mill has come into quite general use.

The Pennsylvania Steel Company was the first works in this country to introduce this practice; the Carnegie Steel Company followed with a much larger mill; The Pennsylvania Steel Company then built one of a large size handling an ingot 36 inches by 48 inches, and the Illinois Steel Company and the Lukens Iron and Steel Company have lately followed the example.

It is difficult to say just what should be the size of the slab for a given plate. Theoretically it would seem immaterial whether a 15-inch ingot is cogged to 8 inches and rolled to one-half inch, or whether it is cogged to 4 inches and rolled to the same thickness. The experiments of Mr. Riley point the same way, but they are far from being comprehensive. If a slab 4 inches thick is not heated to a full heat the plate may be finished at the same temperature as one of the same gauge rolled from a hotter slab of twice the thickness, but in regular practice the thin slabs are sometimes heated hotter than the thick ones, and consequently will be finished at a higher temperature. If carried too far this produces a coarser structure and an inferior metal, so that it is best to proportion the thickness of the slab to the thickness of the plate. The exact relation is of

little importance as long as the reduction is sufficient, for in this matter the old adage is strictly applicable: "Enough is as good as a feast." This will be shown by Tables XIV-C and XIV-D, which investigate the effect of work on billets made from ingots 16 inches square and which thus had an all-sufficient reduction to begin with.

TABLE XIV-C.

Influence of Thickness of Test-Piece on the Physical Properties when the Percentage of Reduction in Rolling is Constant for all Thicknesses; the Finished Bars in each Case having a Sectional Area of about 8 Per Cent. of the Billet.

Heat number.	Size of billet; in inches.	Size of bar; in inches.	Ultimate strength; lbs. per sq. inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.
4605	4x4	2x⅝	51640	51280	33440	35280	37.50	29.50	60.1	50.9
	3½x3⅝	2x½	51120	52340	32650	35410	33.50	33.75	56.4	55.6
	3x3	2x⅝	50850	51970	35700	37860	32.50	30.00	60.8	58.9
	2½x2½	2x¼	58830	58200	37860	41400	31.25	31.50	61.0	66.2
	2x1⅝	2x⅛	. . . .	58850	. . . .	50620	. . . .	19.75	. . .	58.4
9227	4x4	2x⅝	59540	60160	37050	39840	35.00	31.00	60.0	57.4
	3½x3⅝	2x½	59780	60490	38100	40490	29.75	32.50	56.4	55.1
	3x3	2x⅝	60960	61590	42110	42090	30.00	30.50	60.0	55.9
	2½x2½	2x¼	62350	62700	43070	46680	27.50	28.75	60.7	63.3
	2x1⅝	2x⅛	65130	67470	52180	57880	26.25	23.75	58.9	67.5
1509	4x4	2x⅝	67860	68140	42850	44050	25.00	24.25	40.8	43.9
	3½x3⅝	2x½	67550	68040	43190	45560	26.25	28.25	46.1	46.6
	3x3	2x⅝	67470	66800	44090	46610	26.25	28.25	53.3	50.3
1440	4x4	2x⅝	72840	73260	47060	49160	25.00	24.00	40.7	40.8
	3½x3⅝	2x½	71280	73510	46010	50880	26.25	25.00	40.5	43.5
	3x3	2x⅝	72950	73710	48760	50540	26.25	22.00	52.1	43.1
	2½x2½	2x¼	73620	75650	51550	58280	26.25	26.75	45.9	52.1
	2x1⅝	2x⅛	78560	79260	58140	63830	22.75	25.25	52.0	50.4

It will be found from a detailed comparison of these tables that there is little difference between the bars of the same thickness, even though rolled from different-sized billets. There is a gain in ultimate strength as the thickness decreases, this being most marked in the cold-finished bars, but the differences are not very marked except in the case of the one-eighth-inch. The elastic limit follows the same law, but it is raised more than the ultimate as the bar gets thinner. The elongation varies irregularly, but, as a rule, it remains unaffected except in the one-eighth-inch, where it is low-

TABLE XIV-D.

Influence of Thickness of Bar upon the Physical Properties when all Pieces are Rolled from Billets Three Inches Square.

Heat number.	Size of bar; in inches.	Ultimate strength; lbs. per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
		Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.	Finished at usual temperature.	Finished at dull red heat.
4605	2x5/8	51870	50960	32960	38760	34.50	32.75	59.6	56.7
	2x1/2	51070	52480	33200	36050	31.50	30.00	59.2	57.2
	2x3/8	50850	51970	35700	37880	32.50	30.00	60.8	58.9
	2x1/4	52960	52280	36220	40040	31.25	32.50	58.2	58.3
	2x1/8	55560	55000	47380	42500	30.00	29.00	58.2	60.4
9227	2x5/8	59090	60190	37000	40180	35.00	30.00	55.4	56.7
	2x1/2	60850	60510	38560	40470	29.50	32.50	56.8	61.7
	2x3/8	60950	61390	42110	42090	30.00	30.50	60.0	55.9
	2x1/4	62230	63970	42600	49200	25.75	29.25	55.9	61.9
	2x1/8	66340	68180	49860	56180	27.50	24.00	56.6	65.7
1509	2x5/8	65600	67090	40980	45680	29.50	25.50	50.9	44.8
	2x1/2	67810	67660	43090	45170	26.25	25.50	47.1	46.2
	2x3/8	67470	68800	44000	46610	26.25	28.00	58.2	50.3
	2x1/4	69210	70200	47950	52980	26.50	25.25	54.1	56.9
	2x1/8	72100	77460	54060	64480	27.75	15.25	55.0	48.2
1440	2x5/8	72440	74060	46440	49480	27.50	24.00	45.7	42.0
	2x1/2	72670	68150	46200	45990	27.25	28.50	47.2	52.4
	2x3/8	72950	73710	48760	50540	26.25	22.00	52.1	42.1
	2x1/4	75620	71260	51160	54660	25.00	27.25	52.5	49.4
	2x1/8	77500	80240	60920	69980	26.00	18.50	46.8	53.6

TABLE XIV-E.

Effect of Hammering Rolled Acid Open-Hearth Steel.

NOTE.—Chemical composition in per cent.; C, .40; Mn, .86; P, .037; S, .045.

Mark on bar.	Size of billet in inches; being the measure of the side of the square.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 2 inches; per cent. in a section ¾ inch in diameter.	Reduction of area; per cent.	Elastic ratio; per cent.	Remarks.
A	6	54460	89240	29.00	41.2	61.0	Finished at dull yellow.
B	6	41500	88660	28.00	42.2	46.8	Annealed at bright yellow.
C	5	50800	89070	26.50	38.0	57.0	Finished at dull yellow.
D	4	55240	87800	25.50	37.0	63.3	Finished at dull yellow.
E	3	51170	86450	27.50	39.3	59.2	Finished at dull yellow.
F	2	51830	89280	28.00	41.8	58.1	Finished at dull yellow.
G	2	57140	92400	28.00	42.0	61.8	Finished at cherry red.
H	4	45620	89900	27.00	38.9	50.8	Finished at dull yellow.
I	3	47880	88900	25.00	34.3	53.9	Finished at dull yellow.
K	2	51000	88760	27.50	42.7	57.5	Finished at dull yellow
L	5	54020	96400	7.50	5.8	62.5	Annealed at white heat.
M	2	54700	98990	24.50	34.8	58.6	Finished at cherry red.

cred to some extent. The reduction of area is also irregular, but it seems to be independent of the thickness even in the thinnest plate. The conclusion seems justifiable that if the billets have already received sufficient work, the good condition caused thereby is not destroyed by reheating, since bars rolled from them reach their standard level of quality with only a reasonable degree of reduction, as proven by the fact that further work gives no decided improvement. But it is also certain, as shown by all experience, that no harm can be done by increased work, and that there is a slight gain in the long run provided the finishing temperature remains constant.

SEC. XIVd.—*Experiments on forgings.*—The persistency of a proper structure even through subsequent heating may be seen in Table XIV-E, which gives the results obtained from a series of forged billets. The original bloom was 6 inches square, being rolled from an ingot 18″x20″. From this bloom several short pieces were cut and treated in different ways:

A was not reheated, but a test-piece was cut from it as a standard of comparison.

B was heated to a full working heat and cooled without hammering.

C was hammered to 5 inches square in one heat.

D was hammered to 4 inches square in one heat.

E was hammered to 3 inches square in one heat.

F was hammered to 2 inches square in one heat.

G was hammered to 2 inches square in one heat from the annealed bar *B* and was finished at a cherry red heat.

H was hammered to 5 inches square, then reheated and hammered to 4 inches.

I was hammered to 4 inches square, then reheated and hammered to 3 inches.

K was hammered to 3 inches square, then reheated and hammered to 2 inches.

L was hammered to 5 inches square, then overheated and cooled without hammering.

M was made by reheating the burned piece *L* and hammering to 2 inches square in one heat, being finished at a cherry red heat.

All the pieces were worked under a 4-ton double-acting hammer, and the test-bars were cut from the corner of the billet and pulled in a length of 2 inches.

It is quite evident that the pieces which were heated twice, and which received only one inch of reduction after the second heating, must have been finished hotter, as well as have received less work after a full heat, but in spite of these differences in amount of work and temperature it is clear that the bars are practically uniform in strength and ductility, showing that the steel was in thoroughly good condition originally, and that proper heating did no harm when followed by a fair amount of work.

The ultimate strength is fairly uniform save in the case of the two bars which were finished at a cherry red heat. The elastic ratio varies in much greater measure, but the results are not regular since, in some cases, as in *K*, a high ratio accompanies heavy reduction under the hammer, while in others, as in *D*, it appears in bars which have received very little work.

TABLE XIV-F.

Comparative Physical Properties of Test-Pieces of Bessemer Steel Cut from Thick and Thin Angles of Large and Small Sizes.

Each figure is an average of 50 bars.

Thickness of angle.. inches.	Elastic limit: lbs. per sq. in.		Ult. strength: lbs. per sq. in.		Elastic ratio; per cent.		Elongation in 8 in.; per cent.		Reduction of area; per cent.	
	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.	Large sizes.	Small sizes.
½	....	44158	....	61252	....	72.09	....	27.55	....	56.79
⅝	43002	43000	60097	60629	71.55	71.07	28.13	28.55	58.28	54.80
¾	43237	43128	60019	60229	72.70	71.59	28.16	28.52	57.59	57.53
⅞	41671	41634	60120	59151	69.31	70.38	28.58	29.24	55.17	56.96
1	41080	41836	59467	59750	69.08	70.02	28.65	28.74	55.20	57.59
1¼	40801	40944	59360	59084	68.04	69.30	29.08	29.28	58.43	56.07
1½	38867	....	58267	....	66.70	....	28.37	....	51.63	....

The original bar *A* shows a high ratio, but this was finished at a low heat. In the annealed bar *B* the ratio drops very much, but the "burned" bloom *L* shows almost as high an elastic strength as the original steel. In the bar *M*, which should be compared with the bar *G*, it is shown that reheating and hammering will do very much toward restoring a piece of burned steel to its original condition, although it is doubtful whether it ever can make of it a thoroughly reliable material.

SEC. XIVe.—*Tests on Pennsylvania Steel Company angles of different thicknesses.*—The fact that there is very little difference between thick and thin pieces, provided the work has been sufficient in both cases, is shown by Table XIV-F. This was constructed by

taking at random from the records of The Pennsylvania Steel Company the tests on fifty bars of small angles and fifty bars of large angles of each different thickness, of common Bessemer steel, running from .07 to .10 per cent. of phosphorus.

For making the 6″x6″ angles, a bloom 8″x9½″ was rolled from a 16″x20″ ingot, but all other sizes were made from a 7½-inch square bloom which was cogged from a 16″x16″ ingot. The term "small" angles includes 4½″x3″, 4″x4″, and all smaller sizes down to and including 3″x3″; while the "large" embraces from 5″x3″ to 6″x6″, inclusive. The finished area of the smaller bars is such a small part of the original bloom that the reduction may be considered uniform for them all, thus giving a fairly valid basis of comparison for the different thicknesses, while the columns "large" and "small" should show the effect of a varying amount of work on a piece of given thickness.

TABLE XIV-G.

Comparison of Ultimate Strength of Bars Rolled from Test Ingots Six Inches Square, and Test-Pieces Cut from Angles of Different Thicknesses Rolled from the same Heats.

Thickness of angle; in inches.	Number of heats represented.	Elastic limit; lbs. per square inch.			Ultimate strength; lbs. per square inch.			Elastic ratio; per cent.	
		Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.
½ and ⅝	59	42270	41300	970	60200	60190	10	70.28	68.62
⅞ and 1⅛	46	43070	40170	2900	61360	60660	700	70.19	66.22
1⅛ and 1⅝	37	42990	39710	3280	62980	61520	1410	68.31	64.55

It will be noted that the small-sized angles give slightly better results on elongation, but the difference is trifling, while in neither the elastic ratio nor the reduction of area is there any marked superiority. The results indicate that when the amount of work is large, the exact percentage is of little consequence.

The ultimate strength decreases in the thicker angles, but it is not proven that the variation is due entirely to the thickness, for it may be that the heats which were rolled into thick sizes did happen to be of lower strength, but as all the heats were made in the same way, and as both large and small sizes follow the same law, and as

each group includes fifty bars, it seems probable that the gradation represents in some measure the effect of different amounts of work on the material.

TABLE XIV-H.

Comparative Physical Properties of Various Steels, Made by The Pennsylvania Steel Company, when Rolled into Angles of Different Thicknesses.

No. of group.	Kind of steel.	Limits of phosphorus; per cent.	Limits of ultimate strength in group; lbs. per sq. inch.	Thickness of angle; inches.	Number of heats in average.	Average elastic limit; lbs. per sq. inch.	Average ultimate strength; lbs. per sq. in.	Average elastic ratio; per cent.	Average elongation in 8 in.; per cent.	Average reduction of area; per cent.
I	Basic open-hearth.	below .04	47000 to 55000	⅜ to ½	32	30284	52538	69.07	32.18	63.7
				⅝ to ¾	20	34891	53171	65.62	32.33	62.3
				⅞ to 1	14	34026	51908	65.56	32.87	63.4
				1⅛ to 1½	7	32956	51928	62.31	33.86	63.0
II	Basic open-hearth.	below .04	55000 to 63000	⅜ to ½	64	36692	56965	67.43	30.52	56.8
				⅝ to ¾	39	37827	56588	64.62	30.06	56.8
				⅞ to 1	17	37487	56295	63.28	29.28	52.6
				1⅛ to 1½	10	36085	59125	60.95	30.58	55.3
III	Acid open-hearth.	.05 to .07	56000 to 64000	⅜ to ½	212	40691	60845	67.21	29.85	57.4
				⅝ to ¾	126	39415	60695	64.94	29.23	55.6
				⅞ to 1	81	38645	60558	63.81	28.95	53.3
				1⅛ to 1½	121	37478	59906	62.56	29.32	51.2
				1⅝ to 2	8	37798	61943	61.01	28.56	48.7
IV	Acid open-hearth.	.07 to .10	56000 to 64000	⅜ to ½	50	41143	60064	68.50	28.82	58.4
				⅝ to ¾	50	40170	60588	66.30	29.05	56.3
				⅞ to 1	50	39656	61049	64.96	28.98	54.3
				1⅛ to 1½	50	38338	59703	64.15	29.60	55.3
				1⅝ to 2	50	37960	61129	62.11	28.85	50.8
V	Acid Bessemer.	.07 to .10	56000 to 64000	⅜ to ½	150	43417	60659	71.56	28.07	56.6
				⅝ to ¾	200	42518	59882	71.00	28.68	56.3
				⅞ to 1	200	41063	59415	69.11	28.95	55.6
				1⅛ to 2	200	38867	58267	66.70	28.37	51.6
VI	Acid open-hearth.	.05 to .07	64000 to 72000	⅜ to ½	40	43713	65656	66.58	27.90	55.0
				⅝ to 1	29	42191	65681	64.28	27.88	53.7
VII	Acid open-hearth.	.07 to .10	64000 to 72000	⅜ to ½	25	44486	66365	67.08	27.19	55.4
				⅝ to 1	39	42817	65777	65.09	27.49	53.2
VIII	Acid Bessemer.	.07 to .10	64000 to 72000	⅜ to ½	53	46422	66277	70.04	26.42	50 4
				⅝ to 1	28	45280	65940	68.66	27.50	51.5

SEC. XIVf.—*Comparison of the strength of angles with that of the preliminary test-piece.*—That the thin angles will give a higher strength is proven quite conclusively by Table XIV-G, which gives in parallel columns the tests on the finished angles from acid open-hearth heats, and the results obtained from bars rolled from 6-inch square ingots of the same charges. It matters not whether this preliminary test really represents the true value of the steel, for it

may reasonably be assumed that it will give a regular basis of comparison, so that the differences between the results on this standard and on the various thicknesses will be the measure of the effect of rolling.

It is shown that for an increase of one-eighth of an inch in thickness there is a diminution in strength of 700 pounds per square inch. It is, perhaps, as close an agreement as could be expected when we find that in Table XIV-F the difference on the large sizes between the three-eighth-inch and three-quarter-inch angles was 1830 pounds per square inch, or 610 pounds to every one-eighth in thickness, while on the smaller sizes it is 2168 pounds from five-sixteenth-inch to five-eighth-inch, or 434 pounds to every eighth, being an average of 522 pounds for both large and small sizes.

SEC. XIVg.—*Physical properties of Pennsylvania Steel Company steels of various compositions, when rolled into angles of different thicknesses.*—The subject is more fully investigated in Table XIV-H, which gives the average results from angle bars of several different kinds of steel. The accidental variations in the metals make it impossible to compare the influence of the thickness upon the ultimate strength, but the column showing the elastic ratio proves that a lower elastic limit follows an increase in thickness. The elongation remains the same for all thicknesses. The reduction of area varies somewhat, but in the groups where a large number of tests make the figures of much value there is a decrease in the heavier bars.

The variation in strength of the different thicknesses is due in part to the fact that the thin pieces are finished at a lower temperature. The effect of such working is investigated in Tables XIV-C and XIV-D, where pieces of the same billets were heated differently before rolling and were, therefore, finished under unlike conditions. In the bars finished at the lower temperature the elastic limit was raised very considerably, but the ultimate strength and the ductility did not vary much from the hot-rolled bars. This conclusion has nothing to do with the fact so well known to all manufacturers that if a bar or plate is finished so cool that it looks dark in the sunlight it will give a much higher tensile strength; the bars referred to in the table were all finished somewhat hotter than this, and the small variation in temperature seems to have little effect. These conclusions will be corroborated by Table XIV-I, which records certain tests on acid open-hearth steel.

SEC. XIVh.—*Comparative physical properties of hand and guide rounds.*—The fact that the elongation is as high on thick as on thin angles is contrary to a prevailing opinion concerning the effect of surface work upon rolled steel. Further information is given in

TABLE XIV-I.

Effect of Finishing 2x⅜-inch Flats of Acid Open-Hearth Steel at Different Temperatures.

(A = finished at usual temperature. B = finished at a low red heat.)

Group.	Ult. strength; per sq. in.	Heat No.	Composition; per cent.			Ultimate strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			C.	P.	Mn.	A.	B.	A.	B.	A.	B.	A.	B.
I.	56000 to 64000 lbs.	10068	.11	.087	.49	57520	59160	39150	41490	30.50	33.25	63.0	60.9
		10058	.12	.087	.55	57810	61270	39250	44980	32.75	31.75	64.8	58.6
		10055	.12	.080	.65	59060	59140	40800	42760	28.00	30.50	57.9	59.3
		Av.	.12	.085	.56	58130	59857	39733	43077	30.42	31.83	61.9	59.6
II.	60000 to 64000 lbs.	10065	.11	.056	.48	60840	63160	41540	44280	29.25	29.00	61.8	56.5
		10064	.11	.062	.48	60900	63500	41500	45890	30.25	30.50	60.6	58.2
		10071	.13	.065	.48	62230	63820	42290	46730	32.00	30.00	58.9	60.2
		10066	.12	.074	.50	62840	63860	42610	44000	29.25	30.75	61.5	57.3
		Av.	.12	.064	.48	61708	63585	41985	45213	30.19	30.06	60.7	57.6
III.	72000 to 80000 lbs.	10041	.23	.047	.77	72780	74500	47010	49090	25.50	28.75	59.5	57.1
		10045	.23	.052	.86	73060	75910	48660	54240	25.75	28.00	57.8	51.9
		10043	.21	.049	.75	73840	75840	48580	49900	24.00	28.25	55.3	54.6
		10061	.25	.062	.68	75200	77280	49400	51600	25.50	28.50	50.7	54.8
		10064	.25	.059	.78	76960	79480	49340	54920	22.50	27.50	54.4	51.2
		10047	.25	.045	.80	77340	80260	49460	54800	23.75	26.75	52.3	52.4
		10068	.26	.062	.79	78280	80880	50860	57220	26.00	27.50	48.6	47.4
		10042	.26	.042	.76	78540	80560	49980	54900	24.25	24.00	53.8	49.3
		Av.	.24	.052	.77	75688	78083	49155	53884	24.66	27.41	54.1	52.3

TABLE XIV-J.

Comparative Physical Properties of Hand Rounds and Guide Rounds from the Same Acid Open-Hearth Heats.

Group.	Limits of ult. strength in group; pounds per sq. inch	Number of heats in group.	Average manganese; per cent.	Ultimate strength; lbs. per sq. inch.		Elastic limit; lbs. per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
				Hand.	Guide.	Hand.	Guide.	Hand.	Guide.	Hand.	Guide.
I	56000 to 64000	8	.41	59880	59192	42548	38848	28.28	29.35	55.90	61.85
II	70000 to 75000	5	.76	72464	69750	48024	45601	22.77	24.73	40.77	46.98
III	75000 to 80000	5	.81	78805	77790	51943	51983	23.55	24.92	46.09	58.20
IV	80000 to 86000	6	.79	83813	82594	52986	52968	22.74	24.51	45.69	55.57
Av. of all heats,		19	.78	75722	74232	49758	48495	23.83	25.44	46.11	54.28

Table XIV-J, which shows the comparative results on hand and guide rounds from the same heats.

A guide round is made in one pass from an ellipse, while a hand round is put through the same pass several times, being turned one-quarter way each time in order to obtain a true circular section. This has the effect of finishing the bar somewhat cooler than a guide

TABLE XIV-K.

Changes in the Physical Properties of Steel by Variations in the Details of Plate-Rolling; Classified According to Strength of Preliminary Test.

Limits of ult. strength of preliminary test; lbs. per square inch.		Thickness of plate; in inches.	Number of heats tested.	Increase in ultimate strength from preliminary test to plate; pounds per square inch.	Ultimate strength; lbs. per sq. in.			Elastic limit of plate; lbs. per square inch.	Elastic ratio of plate; per cent.	Elongation of plate in 8 inches; per cent.	Reduction of area of plate; per cent.
					Finished plate.	Preliminary test bar.	Average increase from preliminary test to plate.				
Basic open-hearth steel.	44000 to 53000	⅞	12	more than 7500	60040	49479	10561	44659	74.4	25.94	52.9
			18	less than 7500	56475	51177	5298	42570	75.4	26.81	52.3
		¾	13	more than 5500	57807	50020	7787	40407	69.9	26.94	57.4
			19	less than 5500	54799	51033	3766	39675	72.4	28.78	61.1
	53000 to 63000	⅞	94	more than 4000	59582	54096	5486	44053	74.9	26.44	59.6
			68	less than 4000	58328	55741	2582	43028	73.8	27.10	55.3
		¾	69	more than 3000	58705	54013	4692	40420	68.9	28.50	56.9
			60	less than 3000	57021	55328	1693	40266	70.6	28.37	57.8
		⅝	10	more than 3000	59414	53557	5857	38222	64.3	28.09	59.9
			16	less than 3000	56501	54786	1715	36525	64.6	30.58	58.5
		½	7	more than 3000	59185	53984	5201	38078	64.4	27.90	57.9
			10	less than 3000	56977	55840	1137	36770	64.5	27.13	52.5
Acid open-hearth steel.	53000 to 64000	¾	8	more than 2000	62228	59506	2722	42687	68.6	25.69	51.0
			4	less than 2000	61425	60550	875	42825	68.9	25.41	51.0
		⅞	11	more than 1000	61827	59706	2121	42027	68.0	25.12	58.2
			9	less than 1000	59022	59820	....	39675	67.6	24.46	55.5
		½	19	more than 1000	61174	59573	1601	40157	65.7	24.19	50.2
			14	less than 1000	60298	60408	....	39608	65.8	24.69	48.7

round, and thus naturally gives a higher ultimate strength, while it also works the skin of the piece during the finishing process without any great reduction in diameter. It will be seen that nothing is gained by this operation, for, although the guide rounds are slightly reduced in strength, they are considerably better in elongation and reduction of area.

SEC. XIVi.—*Changes in the physical properties of steel by vari-*

ations in the details of plate-rolling.—It has been already stated that it is the practice at The Pennsylvania Steel Works to roll a preliminary test-bar from each open-hearth heat for physical testing, and that the ultimate strength of this bar corresponds closely with that of angles rolled from the same charge. In the case of plates, on the contrary, there is often a considerable variation, and Table XIV-K investigates the effect of such differences upon the physical qualities.

TABLE XIV-L.

Changes in the Physical Properties of Steel by Variations in the Details of Plate-Rolling; Classified According to Strength of Finished Plate.

Limits of ult. strength of finished plate; pounds per square inch.		Thickness of plate in inches.	Number of heats tested.	Increase in ultimate strength from preliminary test to plate; pounds per square inch.	Ultimate strength; pounds per square inch.			Elastic limit of plate; pounds per square inch.	Elastic ratio of plate; per cent.	Elongation of plate in 8 inches; per cent.	Reduction of area of plate; per cent.
					Finished plate.	Preliminary test bar.	Av. increase from preliminary test to plate.				
Basic open-hearth steel.	50000 to 58000	⅝	35	more than 4000	56971	51963	5008	43106	75.6	26.66	57.8
			30	less than 4000	56652	54680	1972	41345	73.0	27.35	55.2
		¾	42	more than 3000	56370	52161	4209	40887	71.6	28.28	58.5
			49	less than 3000	55058	54441	1517	39759	71.0	28.66	58.2
		⅞	7	more than 1700	55963	53391	2572	37613	67.2	30.27	58.6
			6	less than 1700	58981	58213	768	34802	64.5	31.43	59.6
		1	8	more than 1100	56033	54076	2557	36366	64.2	27.91	54.7
			4	less than 1100	55292	54843	449	36150	65.4	28.50	58.7
	58000 to 64000	⅝	39	more than 4000	60180	54284	5896	44572	74.1	26.63	58.7
			38	less than 4000	59844	56401	2943	44054	74.2	26.92	56.3
		¾	15	more than 3000	59750	53676	6074	40928	68.5	27.87	57.6
			15	less than 3000	58920	56969	1951	40855	69.3	28.07	58.7
Acid open-hearth steel.	56000 to 64000	¾	6	more than 2550	62841	59151	3690	43088	69.9	25.92	50.5
			6	less than 2550	61080	60557	523	41900	67.4	25.04	52.0
		⅞	9	more than 1400	61833	59647	2186	42512	68.7	25.28	54.9
			11	less than 1400	59527	59439	88	40280	67.6	24.45	53.8
		1	17	more than 1700	61241	59442	1799	40110	65.5	24.38	50.7
			16	less than 1700	60331	60442	. . .	39800	66.0	24.43	48.6

It is assumed that the preliminary test-piece is the standard, and whatever difference from this is shown in the plate is due to the conditions of rolling. On this basis it is possible to compare those plates which show a great with those which show a less variation

from the standard, and note the corresponding ductility. In the first division, for example, it was found that the average increase in strength from the preliminary bar to the finished plate was 7500 pounds per square inch. Consequently this figure was taken as a dividing line, and a comparison was made of the heats showing more than this difference with those showing less. The same rule was followed in all the other divisions.

Table XIV-L gives a different view of the same data, the groups being divided on the less logical but more practical basis of the

TABLE XIV-M.

Comparative Physical Properties of Angles and Sheared Plates, both being made from Pennsylvania Steel Company Steel.

	Thickness of bar; in inches.	Kind of piece.	No. of heats in average.	Ult. strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per ct.
Basic open-hearth soft steel, below .04 per cent. in phosphorus.	⅝ to ¾	Angles	32	52533	36284	69.07	32.18	63.7
		Plates	107	54998	39017	69.12	29.28	58.0
	¼ to ½	Angles	20	53171	34891	65.62	32.33	62.3
		Plates	102	55017	34947	63.52	29.03	61.5
Basic open-hearth medium steel, below .04 per cent. in phosphorus.	⅝ to ¾	Angles	64	58865	39692	67.43	30.52	58.8
		Plates	265	58271	40849	69.24	28.27	58.1
Acid open-hearth soft steel, below .08 per cent. in phosphorus.	⅝ to ¾	Angles	212	60845	40891	67.21	29.35	57.4
		Plates	190	60217	43278	71.87	25.98	57.4
	¼ to ½	Angles	126	60695	39415	64.94	29.23	55.6
		Plates	59	60768	39061	64.28	25.57	55.1
	⅝ to ¾	Angles	81	60558	38645	63.81	28.95	58.8
		Plates	13	60666	37962	62.58	24.67	52.7

strength of the finished plate. It will be seen that the elongation for a given tensile strength is not seriously affected by the variations in rolling, but that the hotter finished plates are somewhat better. The elastic ratio exhibits much less variation than would be expected, and this might throw some doubt on the results, but all the different groups teach the same lesson, and in some of them the number of heats is so large as to give great weight to the conclusion. The plates were all rolled from slabs, which in turn had been rolled from large ingots, so that there was ample work on all thicknesses.

SEC. XIVj.—*Comparative physical properties of plates and*

angles.—It is very difficult to make a comparison of two different structural shapes, since it does not often happen that the same heat is rolled into more than one kind of section, but an attempt is made to do this in Table XIV-M. The prime requisite is that the steel in both cases shall be of the same manufacture, and this specification is satisfied in the present instance. The figures for the angles are found by combining certain groups in Table XIV-H, which was compiled from the records of The Pennsylvania Steel Company, while the plates represent the average obtained from The Paxton Rolling Mill, which was running on slabs from the same works.

The one predominant feature is the lower elongation in the plates. This may be explained by the fact that the metal receives a less thorough compression in the plate train than it does in the rolling of angles, in which latter case it undergoes a certain amount of lateral thrust.

SEC. XIVk.—*Effect of thickness on the physical properties of plates.*—The effects caused by variations in rolling temperature appear in their most marked degree in the comparison of plates of different gauges. It is not customary to test the same heat in several sizes, but by long experience the manufacturer is able to judge the relative properties of each thickness. The heads of two widely-known plate mills have given me as their estimate that, taking one-half inch as a basis, there will be the following changes in the physical properties for every increase of one-quarter inch in thickness:

(1) A decrease in ultimate strength of 1000 pounds per square inch.

(2) A decrease in elongation of one per cent. when measured in an 8-inch parallel section.

(3) A decrease in reduction of area of two per cent.

W. R. Webster* gives the same data on ultimate strength, but does not mention the relation of section to elongation.

It is, therefore, plain that in the writing of specifications some allowance must be made for these conditions, since a requirement which is perfectly proper for a three-eighth-inch plate will be unreasonable for a 1½-inch. Moreover, the effect is cumulative, since a harder steel must be used in making the thick plate and

* *Observations on the Relations between the Chemical Constitution and Ultimate Strength of Steel. Journal I. and S. I.*, Vol. I, 1894, p. 329.

this will tend to lessen the ductility rather than make up for the reduction caused by the larger section. In plates below three-eighths inch in thickness it is also necessary to make allowances, since it is almost impossible to finish them at a high temperature, and the test will give a high ultimate strength and a low ductility.

These conditions have now been officially recognized by the United States Government, for the rules of the Board of Supervising Inspectors, issued January, 1899, contain the following clause:

"The sample must show, when tested, an elongation of at least 25 per cent. in a length of two inches for thicknesses up to one-quarter inch, inclusive; and in a length of four inches, for over one-quarter to seven-sixteenths, inclusive; and in a length of six inches, for all thicknesses over seven-sixteenths inch and under 1¾ inches."

It is to be hoped that constructive engineers will follow this example in recognizing the influence of causes over which the manufacturer has no control.

CHAPTER XV.

HEAT TREATMENT.

Within the last few years there have been radical advances in our knowledge of the structure of steel and the influence exerted by what has come to be known as "heat treatment." The main principles of this branch of metallurgy have been understood for quite a long time, but they were applied only in exceptional cases, such as the manufacture of guns and armor plate. To-day progressive manufacturers are using the results of research in improving the quality of their ordinary forgings and castings, and it is therefore necessary to consider at some length the general underlying principles of the science of micro-metallography. This has been done in the latter half of this chapter, the article being written by my brother, J. W. Campbell.

The introduction of accurate determinations of temperatures and a better knowledge of the proper heat to use, has to a certain extent diminished the value of the experiments and investigations published in the first edition of this book, but I believe they may be worth recording again, as it is quite certain that many non-progressive works will follow the common and ancient methods of annealing both at the forge of the smith and on a larger scale in the treatment of eye bars and similar material. In the following sections the word "annealing" is used unless otherwise stated to signify that the piece was heated in a muffle heated by a soft coal fire, the bar being withdrawn when it had reached a dull yellow heat. The experiments were carefully performed and it is believed that the practice was fairly uniform.

SECTION XVa.—*Effect of annealing on the physical properties of rolled bars.*—It is a well known fact that annealing tends to remove the strains which are created by cold rolling and distortion, but it is not generally understood how profound are the changes

produced. Table XV-A will show the results obtained on rounds and flats by comparing the natural bar with the annealed specimen

TABLE XV-A.

Effect of Annealing on Rounds and Flats of Bessemer and Acid Open-Hearth Steel.

A 4"x4" billet from each heat was rolled into a 2"x⅝" flat and another into a ¾ round.

	Limits of ultimate strength; pounds per square inch.	Kind of steel.	Number of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾-inch rounds.	56000 to 60000	Bess.	11	Natural	58869	42818	27.75	58.83	71.86
				Annealed	55706	37828	29.14	66.55	67.91
		O. H.	4	Natural	56568	40800	29.69	60.78	68.81
				Annealed	54096	31828	28.75	62.65	58.83
	60000 to 64000	Bess.	6	Natural	62067	45828	27.04	55.81	73.00
				Annealed	59872	40570	30.18	65.50	68.33
		O. H.	7	Natural	62187	42606	28.04	62.16	68.51
				Annealed	58364	35120	28.61	63.47	60.17
	64000 to 68000	Bess.	9	Natural	66241	47568	26.08	50.07	71.81
				Annealed	61694	42228	28.25	62.91	68.45
	68000 to 72000	Bess.	8	Natural	70457	50268	24.75	48.30	71.34
				Annealed	65908	44660	26.08	63.23	67.76
		O. H.	2	Natural	70580	49000	26.88	61.10	69.47
				Annealed	65500	37685	28.88	65.30	57.58
	72000 to 80000	Bess.	4	Natural	77440	53760	24.06	42.35	69.42
				Annealed	71548	47648	25.81	57.58	66.59
		O. H.	12	Natural	76616	51108	24.52	58.73	66.71
				Annealed	69402	40505	28.04	66.54	58.36
2x⅝-inch flats.	56000 to 60000	Bess.	11	Natural	58458	41698	31.45	56.13	71.33
				Annealed	54194	35608	30.05	63.13	65.70
		O. H.	4	Natural	58120	40400	30.13	61.75	69.51
				Annealed	51418	30898	31.06	60.50	59.11
	60000 to 64000	Bess.	6	Natural	60825	43135	30.42	56.20	70.92
				Annealed	56192	37542	30.68	63.38	66.81
		O. H.	7	Natural	62069	42441	30.14	60.86	68.36
				Annealed	55021	31576	30.86	60.00	57.39
	64000 to 68000	Bess.	9	Natural	64621	45194	28.42	47.80	69.94
				Annealed	59888	38476	28.86	59.01	65.39
	68000 to 72000	Bess.	8	Natural	69773	49060	26.67	48.40	70.31
				Annealed	64160	43770	28.53	59.50	68.22
		O. H.	2	Natural	69420	45090	25.68	59.30	64.96
				Annealed	60650	34000	26.50	52.10	55.87
	72000 to 80000	Bess.	4	Natural	76900	52240	23.44	40.15	67.93
				Annealed	68780	43568	26.88	51.00	63.34
		O. H.	12	Natural	75865	49691	24.69	54.40	65.50
				Annealed	67618	39408	26.81	51.06	58.27

when all the pieces were rolled from billets of the same size and on the same mill.

The decrease in ultimate strength by annealing the Bessemer bars averaged 4175 pounds per square inch in the rounds and 5683 pounds in the flats, while the open-hearth was lowered 5134 pounds in the rounds and 7649 in the flats. In this important and fundamental quality the two kinds of steel are very similarly affected, but in other particulars there seems to be a radical difference which is difficult to explain.

TABLE XV-B.

Comparison of the Natural and Annealed Bessemer Steel Bars Given in Table XV-A, which show about the same Ultimate Strength.

	Group.	Limits of ultimate strength in group; pounds per square inch.	No. of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾-inch rounds.	I	56000 to 60000	11 17	Natural Annealed	58889 56998	42318 38796	27.75 29.49	58.83 66.18	71.88 68.06
	II	60000 to 64000	6 9	Natural Annealed	62087 61694	45823 42228	27.04 28.25	55.31 62.91	73.09 68.45
	III	64000 to 68000	9 8	Natural Annealed	66241 65908	47568 44660	26.08 26.08	50.07 63.23	71.81 67.76
	IV	68000 to 72000	8 4	Natural Annealed	70457 71548	50263 47643	24.75 25.81	48.30 57.53	71.34 66.59
2x⅝-in. flats.	V	56000 to 60000	11 15	Natural Annealed	58458 57780	41698 38102	31.45 29.27	56.13 60.76	71.33 65.95
	VI	64000 to 68300	9 8	Natural Annealed	64621 64160	45104 43770	28.42 28.58	47.80 59.50	69.94 68.22
	VII	68000 to 72000	8 4	Natural Annealed	69773 68780	49060 43503	26.67 26.88	48.40 51.00	70.31 63.34

The elongation of the Bessemer steel is increased by annealing in every case except two, the average being 1.33 per cent., while the open-hearth metal shows a loss in three cases, with an average loss for all cases of 0.21 per cent. This is not very conclusive, but there is a more marked difference in the reduction of area, for in the Bessemer steel there is an increase in the annealed bar in every case varying from 7 to 15.18 per cent., while the open-hearth

showed an increase in only three cases, the maximum being 2.81 per cent., and a decrease in five cases, the greatest loss being 7.20 per cent.

The elastic limit fell much more than the ultimate strength, and here again the Bessemer seems to be different from the open-hearth steel, for while the elastic ratio of the former is lowered from 2.1 to 4.7 per cent. by annealing, the latter loses from 7.2 to 11.9 per cent. It will not do to draw a general conclusion from these limited data on the nature of the two kinds of steel, but whether

TABLE XV-C.

Comparison of the Natural and Annealed Open-Hearth Steel Bars Given in Table XV-A, which show about the same Ultimate Strength.

	Group.	Limits of ultimate strength in group; pounds per square inch.	Number of heats in average.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; Per cent.
¾-inch rounds.	I	56000 to 60000	4 7	Natural Annealed	58568 58364	40800 35120	29.69 28.61	60.78 63.47	69.81 60.17
	II	68000 to 72000	2 12	Natural Annealed	70580 69402	49000 40505	26.88 23.04	61.10 56.54	69.47 58.36
2×⅝-inch flats.	III	55000 to 60000	4 7	Natural Annealed	58120 55021	40400 31576	30.13 30.86	61.75 60.00	69.51 57.39
	IV	60000 to 64000	7 2	Natural Annealed	62089 60850	42441 34000	30.14 26.50	60.86 52.10	68.36 55.87
	V	66000 to 70000	2 12	Natural Annealed	69420 67618	45090 30408	25.63 26.31	59.80 51.26	64.96 58.27

further experiment would or would not corroborate these results, it is quite certain that annealing under ordinary conditions, even though very carefully conducted, may produce grave differences in physical properties in steels of similar composition which have been rolled in the same manner and treated at the same time, even when the effect upon the ultimate strength has been the same.

It would also appear that in the Bessemer steel the marked increase in ductility is purchased at a great sacrifice of strength, and the question arises whether the gain is not more than balanced by the loss, and whether an equal degree of toughness could not be

secured by using a softer steel in its unannealed state. A comparison of the natural and annealed bars of corresponding tensile strength in Table XV-A will give the results shown in Tables XV-B and XV-C.

SEC. XVb.—*Effect of annealing on bars rolled at different temperatures.*—These results show that the annealed bar has a very much lower elastic limit than a natural bar of the same ultimate strength, and oftentimes has less ductility. The difference between the Bessemer and open-hearth steels cannot be due to irregular

TABLE XV-D.

Effect of Annealing Acid Open-Hearth Rolled Steel Bars 2x⅜ inches.

Group.	No. of heats in group.	Limits of tensile strength; pounds per square in. and composition; per cent.	Temperature at which bars were finished.	Condition of bar.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
I	3	56000 to 60000 C, .12; P, .065; Mn, .56.	Usual	Nat.	56130	39738	30.42	61.90	68.4
				Ann.	52328	31677	30.75	60.62	60.5
			Dull red	Nat.	59857	42037	31.88	59.60	71.9
				Ann.	51557	33898	32.92	63.60	65.7
II	4	60000 to 64000 C, .12; P, .086; Mn, .48.	Usual	Nat.	61708	41985	30.19	60.70	68.0
				Ann.	54468	30958	30.38	59.35	56.8
			Dull red	Nat.	63585	45213	30.06	57.58	71.1
				Ann.	55058	36966	30.94	61.58	67.3
III	8	72000 to 80000 C, .24; P, .052; Mn, .77.	Usual	Nat.	75688	49155	24.66	54.05	64.9
				Ann.	66584	37984	26.06	50.74	57.0
			Dull red	Nat.	78088	53334	27.41	52.22	68.3
				Ann.	67058	40843	26.50	53.41	60.9

finishing, since all the bars were rolled at the same time, and further experiments given in Table XV-D indicate that the same law holds good whether the metal is finished hot or cold.

In the bars which are finished at the usual temperature there is a loss in strength due to annealing of from 6000 to 9000 pounds per square inch, and a lowering in the elastic limit of from 8000 to 11,000 pounds. In the colder finished bars the loss in strength is from 8000 to 11,000 pounds, and the elastic limit is lowered from 8000 to 13,000 pounds. Thus in both cases the elastic limit is affected much more than the ultimate strength, and the

result is seen in a lower elastic ratio. The ductility does not seem to be materially improved in any instance.

The cold finishing raised the strength of the bars 1727 pounds per square inch in Group I, 1882 pounds in Group II, and 2395 pounds in Group III. Annealing lowered the strength of these cold-finished bars so that in Group I it was 766 pounds per square inch below the annealed hot-finished bar, while in Group II it was

TABLE XV-E.

Effect of Annealing on Bars of Different Thickness, when the Percentage of Reduction in Rolling had been Constant for all Pieces.

Heat number.	Size of billet in inches.	Size of bar in inches.	Ultimate strength; lbs. per sq. inch.		Elastic limit; lbs. per sq. inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
			Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
4605	4x4	2x⅝	51640	45870	33440	25680	37.50	37.50	60.1	64.8
	3⅝x3⅝	2x½	51120	45100	33650	26850	32.50	38.00	56.4	64.0
	3x3	2x⅝	50850	46850	33700	25080	32.50	39.50	60.8	67.0
	2½x2½	2x¼	53830	46010	37800	26680	31.25	34.00	61.0	64.8
	2x1⅝	2x⅛	. . . .	44960	. . . .	28570	. . . .	31.25	. . . .	67.2
9227	4x4	2x⅝	59540	53360	37050	29080	35.00	33.50	60.0	59.7
	3⅝x3⅝	2x½	59730	51360	38100	28410	29.75	32.75	56.4	60.1
	3x3	2x⅝	60050	52460	42110	29860	30.00	31.75	60.0	56.6
	2½x2½	2x¼	62850	51280	43070	28580	27.50	30.00	60.7	62.4
	2x1⅝	2x⅛	65180	54110	52180	31170	26.25	28.25	58.9	64.9
1509	4x4	2x⅝	67860	63560	42950	28750	25.00	26.50	40.8	57.2
	3⅝x3⅝	2x½	67550	62680	43190	28810	26.25	29.00	46.1	58.4
	3x3	2x⅝	67470	62660	44090	40480	26.25	29.25	53.2	56.1
1440	4x4	2x⅝	72840	68940	47080	42580	25.00	27.00	40.7	58.6
	3⅝x3⅝	2x½	71280	67060	46010	43020	26.25	29.00	40.5	58.4
	3x3	2x⅝	72950	67860	48760	43920	26.25	26.25	52.1	55.4
	2½x2½	2x¼	73630	69720	51550	43980	26.25	25.50	45.9	54.1
	2x1⅝	2x⅛	78560	74000	56140	53200	22.75	25.25	52.0	58.6

595 pounds above it, and in Group III 474 pounds. The effect upon the elastic limit is not as thorough, and the influence of the cold finishing may be seen in the higher elastic ratio of the annealed cold-finished bar.

SEC. XVc.—*Effect of annealing on bars rolled under different conditions of work and temperature.*—All these results will be corroborated by Tables XV-E and XV-F, which show the effect of annealing on bars which have been finished under different conditions. In Table XV-E, where each bar was made from a billet

of proportionate size, the pieces would be in the rolls about the same length of time, so that the only difference in character will be due to the more rapid loss in heat from a thin bar and from the more thorough compression. In Table XV-F, where all bars were rolled from the same-sized billet, these factors are supplemented by the extra cooling during the longer exposure in the rolls.

TABLE XV-F.

Effect of Annealing on Bars of Different Thickness, when All Pieces had been Rolled from Billets 3 inches Square.

Heat Number.	Size of Bar in Inches.	Ult. strength; lbs. per sq. inch.		Elastic limit; lbs. per sq. inch.		Elongation in 8 in.; per cent.		Reduction of area; per ct.	
		Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
4005	2x5/8	51370	45490	32860	25560	34.50	36.75	59.6	65.6
	2x1/2	51070	48280	38200	24110	31.50	38.00	59.2	64.2
	2x3/8	50850	46350	35700	25980	32.50	39.50	60.8	67.0
	2x1/4	52960	44470	36220	. . . .	31.25	38.50	63.2	69.6
	2x1/8	55560	45630	47380	27780	30.00	33.25	53.2	69.0
9227	2x5/8	59690	52380	37000	29080	35.00	32.00	55.4	56.4
	2x1/2	60850	52270	38560	28460	29.50	32.00	58.8	55.1
	2x3/8	60950	52460	42110	29860	30.00	31.75	60.0	56.6
	2x1/4	62280	58500	42600	31000	25.75	30.75	55.9	56.4
	2x1/8	66340	54810	49860	30000	27.50	26.25	56.6	61.6
1509	2x5/8	65600	61480	40980	37840	29.50	29.00	50.9	57.1
	2x1/2	67810	64500	43090	41400	26.25	29.25	47.1	56.0
	2x3/8	67470	62660	44090	40430	26.25	29.25	53.2	56.1
	2x1/4	69210	65240	47950	44510	26.50	30.50	54.1	52.6
	2x1/8	72100	66940	54060	49000	27.75	27.50	55.0	53.6
1440	2x5/8	72440	69730	46440	45250	27.50	24.25	45.7	56.3
	2x1/2	72570	67980	46200	43000	27.25	28.25	47.3	54.2
	2x3/8	72950	67860	48760	43020	26.25	26.25	52.1	55.4
	2x1/4	75620	71560	51160	48250	25.00	26.50	53.5	59.0
	2x1/8	77500	70820	60920	56420	26.00	25.50	46.8	59.9

SEC. XVd.—*Effect of annealing on plates of the same charge which showed different physical properties.*—This matter of finishing temperature is of supreme importance in filling specifications on structural material, more especially in the rolling of thin plates, for it will often happen that different members of one heat will show wide variations in tensile strength when the metal itself is practically homogeneous. Table XV-G will illustrate this point by giving the records of test-pieces which gave the greatest variations in any one heat, and comparing the natural bar with a piece of the same strip when annealed.

It will be seen that annealing has almost wiped away the variations in each heat, and it is therefore quite certain that the differences lie in the rolling history. The true way of testing the

TABLE XV-G.

Showing that Rolled Plates of the same Acid Open-Hearth Heat, which show Wide Variations in their Physical Properties, are made alike by Annealing.

NOTE.—In each case, *A* is the test giving the highest tensile strength of any plate in the heat, and *B* is the one giving the lowest. Carbon was determined by color and is therefore not reliable.

Heat number.	Thickness of plates.	Condition of test bar.	Test mark.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Chemical composition; per cent.			
									C.	P.	Mn.	S.
5688	½	Natural	A	61000	58200	21.50	61.9	87.2	.16	.015	.32	.022
		Natural	B	56480	46800	25.25	60.0	82.0	.12	.015	.31	.019
		Annealed	A	47750	29980	34.50	67.0	62.8	. . .	. . .	. . .	. . .
		Annealed	B	46070	30690	35.00	64.5	65.3	. . .	. . .	. . .	. . .
5668	½	Natural	A	65870	52560	21.75	58.7	80.4	.14	.009	.45	.025
		Natural	B	60880	48800	21.50	61.1	80.8	.10	.012	.45	.020
		Annealed	A	52160	32450	32.00	57.0	62.2	. . .	. . .	. . .	. . .
		Annealed	B	50260	33840	32.50	62.6	66.3	. . .	. . .	. . .	. . .
6217	½	Natural	A	64620	53140	25.00	58.1	82.2	.16	.021	.44	.031
		Natural	B	59960	48490	21.50	45.5	80.9	.14	.016	.44	.025
		Annealed	A	52820	35450	27.00	62.2	67.1	. . .	. . .	. . .	. . .
		Annealed	B	50000	31840	31.50	56.4	63.7	. . .	. . .	. . .	. . .
6226	½	Natural	A	64260	54370	21.00	50.6	84.6	.12	.026	.34	.056
		Natural	B	57040	39990	23.75	56.6	70.1	.12	.024	.32	.047
		Annealed	A	54070	38520	27.50	64.4	71.2	. . .	. . .	. . .	. . .
		Annealed	B	53960	38520	29.50	68.3	71.4	. . .	. . .	. . .	. . .
6231	⅜	Natural	A	64480	50560	26.00	58.8	78.4	.18	.021	.55	.048
		Natural	B	61100	45080	26.00	48.0	73.7	.11	.018	.51	.044
		Annealed	A	53930	34870	31.25	61.9	64.8	. . .	. . .	. . .	. . .
		Annealed	B	52180	33780	34.25	63.2	64.7	. . .	. . .	. . .	. . .
6233	½	Natural	A	66360	50100	20.75	52.7	89.1	.11	.026	.37	.033
		Natural	B	56160	47680	24.50	60.3	81.9	.11	.020	.39	.028
		Annealed	A	52760	36940	33.00	65.0	70.0	. . .	. . .	. . .	. . .
		Annealed	B	51480	40480	28.75	56.0	78.6	. . .	. . .	. . .	. . .
6234	⅜	Natural	A	66800	49440	20.75	57.5	74.6	.15	.024	.49	.023
		Natural	B	61360	47980	27.00	61.7	78.1	.14	.021	.47	.023
		Annealed	A	55560	37360	28.25	60.0	67.2	. . .	. . .	. . .	. . .
		Annealed	B	54068	34448	31.75	63.7	63.7	. . .	. . .	. . .	. . .
6235	½	Natural	A	68220	56800	18.50	54.9	92.2	.10	.017	.33	.035
		Natural	B	58240	47680	21.25	53.5	81.8	.11	.017	.35	.034
		Annealed	A	47740	29060	33.25	63.9	62.7	. . .	. . .	. . .	. . .
		Annealed	B	47600	30530	34.00	57.2	64.1	. . .	. . .	. . .	. . .
6236	⅜	Natural	A	64020	49510	23.25	58.1	77.3	.11	.025	.46	.037
		Natural	B	58720	42960	30.25	60.0	73.2	.13	.017	.45	.022
		Annealed	A	58960	38710	29.25	58.6	63.6	. . .	. . .	. . .	. . .
		Annealed	B	50960	32710	35.00	64.7	64.6	. . .	. . .	. . .	. . .

homogeneity of steel, or of comparing two different samples, is to make the tests on annealed bars. This practice was pursued in Chapter XIII.

SEC. XVe.—*Effect of annealing on the physical properties of eye-bar flats.*—It does not follow that plates and bars should be annealed to put them into their best condition. On the contrary, the foregoing tests have shown that very little is gained in ductility, while there is quite a loss in working strength, and that it would be better and much cheaper to choose a softer steel in its natural state. Moreover, it must be considered that the bars which have been discussed in the foregoing tables have been small test-pieces which could be treated under fairly constant conditions, and even then the results are far from regular.

TABLE XV-H.

Comparative Tests of Eye-Bar Steel.

Heat number.	Longitudinal strip; cut from near the edge of eye-bar; natural.					Full-sized eye-bar; annealed.				
	Elastic limit; pounds per square in.	Ultimate strength; pounds per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Elastic limit; pounds per square in.	Ultimate strength; pounds per square in.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
1	40710	68880	27.00	47.18	59.1	36500	62100	43.70	52.60	58.8
2	41570	71400	26.25	50.08	58.2	40400	65300	40.00	46.55	62.0
3	39780	69460	25.75	44.31	57.3	38300	63250	41.85	45.95	60.5
4	40880	69400	25.00	48.41	58.9	40600	67100	36.00	45.00	60.5
5	41480	72820	24.50	46.78	57.4	42100	65000	36.60	48.40	64.8
6	41310	73640	23.75	36.54	56.1	38700	67600	45.60	50.00	58.5
7	40870	72060	25.60	40.00	56.0	35400	64700	45.62	61.20	54.7
8	41900	76700	25.75	43.76	54.6	39600	67700	38.43	42.65	58.5
9	41070	69680	27.00	44.33	58.9	35900	65200	40.00	46.40	55.1
AV.	41008	71499	25.62	44.60	57.4	38056	64206	40 87	46.54	59.3

These deductions will be corroborated by Table XV-H, which gives the parallel records of pieces cut from a flat bar in its natural state, and the full-sized eye-bars after annealing. The steel was made and rolled by one of our largest American works. It is plain that there is a great gain in the elongation, but the reduction of area is unaffected and there is a decided loss in elastic and ultimate strength.

SEC. XVf.—*Methods of annealing.*—A different view of the subject is taken by Gus. C. Henning.* He states that steel is injured

* *Trans. Am. Soc. Mech. Eng.*, Vol. XIII, p. 572.

by annealing if it is in contact with flame, while it is improved if it is reheated in a sealed muffle. I cannot assent to this broad conclusion, for, while it may be true that a flame can be run too hot and the piece be burned through carelessness, it by no means follows that such local overheating is necessary; nor is there any ground for assuming the absorption of deleterious gases from a proper flame. Moreover, the figures which he gives do not show a decided improvement of any kind in the bars which were heated in a retort.

TABLE XV-I.

Comparative Physical Properties of Natural and Annealed Flat Steel Bars; as given by Henning.*

Number of pieces.	Thickness of flats; in inches.	Average thickness of flats; in inches.	Condition of bar.	Elastic limit; pounds per square inch.	Ult. strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
10	$\frac{5}{8}$ to $1\frac{1}{16}$	1.12	Natural	38787	71226	23.89	47.0	54.4
			Annealed	40299	69296	25.53	53.5	58.2
16	$1\frac{1}{8}$ to $1\frac{7}{16}$	1.41	Natural	35411	68465	24.88	46.05	51.7
			Annealed	33298	67071	24.95	49.17	50.3
12	$1\frac{1}{2}$ to $1\frac{5}{8}$	1.62	Natural	35729	69490	24.25	47.27	51.4
			Annealed	33602	60411	25.28	49.85	55.7

It is stated (*loc. cit.*, p. 577) that most of the "flats" were "properly" annealed, and so I have averaged the records which he gives of the natural and the reheated pieces, separating them into three groups according to thickness. The results are given in Table XV-I. It will be seen that the metal has undergone very little change at all, and it is impossible to see anything which can be called a radical improvement.

Any attempt to carry out a general system of annealing plates and shapes will result in wide variations in temperatures and rates of cooling, for it will be impossible to have a large pile of metal heated uniformly throughout, since the outside of the lot will be at

* *Trans. Amer. Soc. Mech. Eng.*, Vol. XIII, p. 586, *et seq.* The factor which Mr. Henning calls the "yield point" is here called the elastic limit. I have omitted from the averages the tests which are noted in the original as being wrongly marked, and also three tests which show such extremely low elongation that it is certain the material was not properly treated, or that there is an error in the records.

a full heat when the interior is unaffected. Since the manufacturer may always manipulate the operation so as to affect the test-pieces in preference to the rest of the steel, and since it will be to his interest to keep the temperature as low as possible to avoid warping, there will be no certainty either that the work has been properly carried out or that it has been of the least advantage.

SEC. XVg.—*Further experiments on annealing rolled bars.*—The experiments on annealing related in this chapter were performed by the usual method of estimating temperatures by the eye. They were, however, conducted under conditions exceptionally favorable to uniform results, as the pieces were small and were enclosed in a muffle and were carefully watched. No ordinary an-

TABLE XV-J.

Effect of Annealing at about 800° C. (1472° F.) on the Physical Properties of Structural Steel. (Bars are rolled flats 2″x⅜″.)

Limits of Ultimate Strength lbs. per sq. inch.	Kind of Steel.	No. of bars.	Condition of bar.	Average ultimate strength lbs. per sq. in.	Average elastic limit lbs. per sq. inch.	Elongation in 4 inches; per cent.	Reduction of area; per cent.	Elastic ratio.
57 to 61,000	Acid open hearth.	10	Natural	60,110	39,770	33.3	52.0	66.1
		15	Annealed	55,690	36,180	36.3	56.8	64.9
56 to 64,000	Basic open hearth.	12	Natural	61,740	38,861	33.0	52.3	63.0
		17	Annealed	57,870	35,320	36.6	57.6	61.0
58 to 68,000	"Transferred." See Section XIIa.	10	Natural	62,059	39,590	33.4	54.9	64.6
		15	Annealed	55,590	34,790	37.3	59.0	62.6

nealing of eye-bars or plates would be carried out under such favorable auspices. For purposes of comparison, I have repeated some of the experiments, the temperatures being determined by the Le Chatelier pyrometer. In Table XV-J it is shown that the heat treatment has reduced the tensile strength, the elastic limit and the elastic ratio, and has raised the elongation and reduction of area. In Table XV-K are compared the bars showing similar ultimate strength. The annealed pieces show greater elongation, but a lower elastic ratio, and in order to obtain the same elastic limit it would be necessary to take a harder steel, whereby the elongation would be somewhat lowered. It would seem doubtful therefore whether the bars under the most careful annealing are

more suitable for structural work than the ordinary product of a mill, while assuredly the extra cost of such careful treatment of long and heavy sections would make it commercially out of the question in almost all cases. It is, of course, understood that the treatment of eye-bars is a different question, this being made necessary by the work done in shaping the ends.

TABLE XV-K.

Comparison of the Natural and Annealed Bars shown in Table XV-J, which show about the same Ultimate Strength.

Limits of Ultimate Strength; lbs. per sq. inch.	Kind of Steel.	No. of bars.	Condition of bars.	Average ultimate strength lbs. per sq. in.	Average elastic limit; lbs. per sq. inch.	Elongation in 4 inches; per cent.	Reduction of area; per cent.	Elastic ratio.
54 to 58,000	Acid.	10	Natural	56,200	39,550	29.7	58.8	70.4
52 to 59 000		15	Annealed	55,690	36 180	36 3	56.8	64.9
55 to 58,000	Basic.	12	Natural	56,870	37,760	30.4	56.4	66.4
54 to 64,000		17	Annealed	57,870	35,320	36.6	57.6	61.0
55 to 60,000	Acid.*	4	Natural	58 130	40 400	30.1	61.7	69.5
55 to 60,000		7	Annealed	55.021	31,576	30.4	60.0	57.4

SEC. XVh.†—*General remarks on the determination of temperatures.*—For the commercial operation of annealing, the temperature may be conveniently and accurately determined by the use of a platinum or copper ball with the usual water receiver. In more accurate work it is advisable to use a Le Chatelier pyrometer, but in either case considerable care must be taken to insure that the piece of metal which registers the temperature, whether it be the ball or the electric couple, is of the same degree of heat as the forging or the casting under treatment.

It is generally taken for granted that if the juncture of a Platinum—Platinum—ten per cent. Rhodium couple is in contact with the steel under treatment, the temperature as registered is correct. Practically, although not absolutely, this is true, for if the conditions of heating are the same, that is, if the furnaces are of the same general size and plan and the pieces under treatment are

* These constitute Group III in Table XV-C.

† The remainder of this chapter is mainly the work of J. W. Campbell.

approximately the same size, the readings are relative, and being relative may be considered to be correct. Now is this true under conditions radically different? If a small piece of steel is placed in a muffle and heated, the muffle having been at a high temperature before the introduction of the piece, it will be found even while the piece is black or very dark red, say not over 650° C., that the needle of a Le Chatelier pyrometer, the couple of which is in contact with the steel, will indicate a temperature some thirty degrees higher. This is probably due to the fact that while it takes some time for the mass of steel to absorb the heat from the muffle, the fine wires of the couple arrive at the high temperature in perhaps twenty or thirty seconds. Of course, the juncture, being in contact with the cooler steel, is considerably cooler than the furnace, but nevertheless it is some degrees higher than the piece, and this higher temperature is the one which sets up the difference of potential which affects the galvanometer.

This is undoubtedly the case in still greater measure with larger furnaces and larger masses, and if it is desired to compare a small piece with a large one the temperature of treatment must be the same. There is one way of arriving at this with certainty, and this is in accordance with what Howe describes as the condition of invisibility. He sets forth that a certain color is indicative of a certain temperature, whatever the material, and proves it by stating that if pieces of several different kinds of metals be placed in a furnace and heated carefully and slowly, and held till it is certain that they are heated equally through and through, on looking into the furnace nothing can be seen but the walls of the furnace. The pieces are invisible. He then shows that since the only light is that given off by the heated surfaces themselves and since if there were even the slightest difference in color, the edges of the pieces could be seen, the whole furnace and contents must be the same color and this he calls "invisibility."

Now if a large piece of metal is heated until the wires of the couple cannot be seen in contact with the piece, and if this heating be continued until the piece shows an uniform color all over its surface, and until it has been heated throughout to this color, an absolute reading is obtained—at least absolute within the limits of error of the galvanometer. In this connection it should be stated that the Le Chatelier pyrometer is the best practical method of taking readings of high temperatures. That a piece

has been heated thoroughly can only be discovered by practice and a knowledge of the heating capacity of the furnace. As good a way perhaps as any is to note the time of heating to a certain indicated temperature, then cool under conditions which may be duplicated and note time of cooling; then heat to this temperature again, soak for some time and cool under previous conditions, and if the cooling takes longer the piece is heated more nearly uniformly. After a few trials in this way the necessary time may be estimated with sufficient accuracy. It may seem that this is an unnecessary refinement, but up to the present time, except in a limited number of grades of steel and at a few works, proper attention has not been given to the annealing of steel.

SEC. XVI.—*Definition of the term "critical point."*—If a piece of steel containing over 0.50 per cent. of carbon be allowed to cool slowly from a high temperature, certain peculiar phenomena will be noticed. The cooling at first proceeds at a uniformly retarded rate, but when a temperature of about 700° C. is reached there is an interruption of this regularity. In some cases the rate of cooling may become very slow, in other cases the bar may not decrease in temperature at all, while in still other cases the bar may actually grow hotter for a moment in spite of the fact that it is free to radiate heat in every direction and that it has been cooling regularly down to that particular temperature. Moreover, it will be found that when this "critical point" is passed, the bar cools as before until it reaches the temperature of the atmosphere. It is, of course, a matter of common knowledge that a bar will cool in less time from 1000° C. to 900° C. than it will from 200° C. to 100° C. and the term "uniformly retarded," as above used, is intended to cover this fact.

It is quite clear that there must be some change taking place within the metal itself giving rise to heat, and any point at which such an action takes place in any steel is called a "critical point" and in metallography such a point is denoted by the letter A, the particular one just described in which there is a retardation in the cooling of a piece of steel being denoted by the term Ar. In heating a piece of steel through this range of temperature, we naturally encounter an exactly opposite phenomenon, there being an absorption of heat by internal molecular reaction, with a consequent retardation in the rise of temperature, and this point is called Ac. It has been shown by Prof. Howe that Ac is some 30° C. higher

than Ar, but it is also found that in order to induce the change Ar the steel must first be heated past the point Ac, while the change at Ac cannot take place unless the steel has first been cooled to a point below Ar. It is clear therefore that these two retardations are simply opposite phases of the same phenomena.

The previous discussion has considered only steels containing as much as one-half of one per cent. of carbon and mention has been made of only one critical point, when as a matter of fact it is quite certain that there are three, although it will be shown later that the three points are practically coincident in steels containing

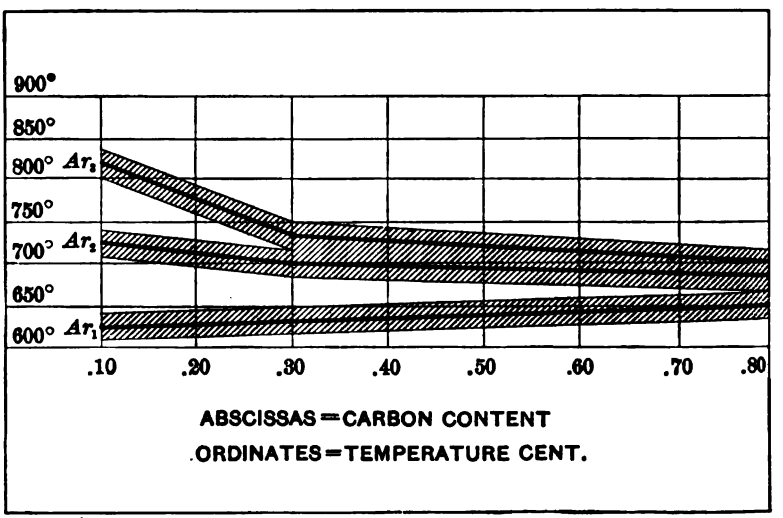


FIG. XV-A.—VARIATIONS IN THE CRITICAL POINTS IN DIFFERENT STEELS.

over 0.30 per cent. of carbon. At one of these points, recently proven to be the second, is the point of magnetic transformation. Below this point carbon steel is attracted by a magnet. Above this point it is attracted only slightly if at all. It has been before explained that the critical points are found at a slightly different temperature according to whether the metal is being heated or being cooled, and it is evident that the point of magnetic transformation, which coincides with the second critical point, will vary in the same way.

In soft steels these three points are readily distinguished, but as

No. 1.

No. 2.

No. 3.

No. 4.

No. 5.

No. 6.

No. 7.

No 8.

No. 9

FIG. XV-B.

No. 10.

No. 11.

No. 12.

No. 13.

No. 14.

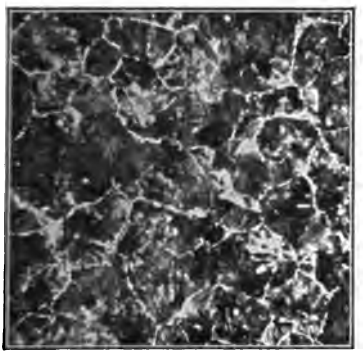
No. 15.

No. 16.

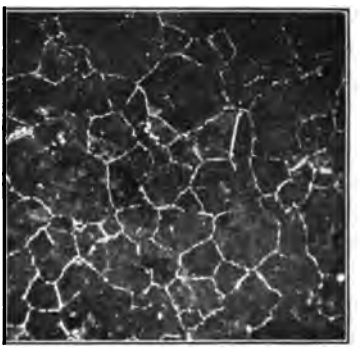
No. 17.

No. 18.

FIG. XV-C.

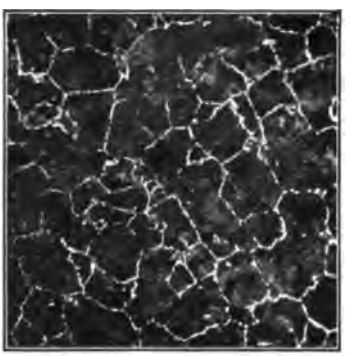


No. 19.

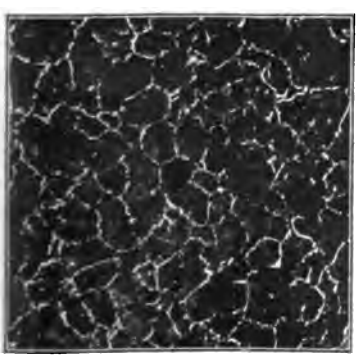


No. 20.

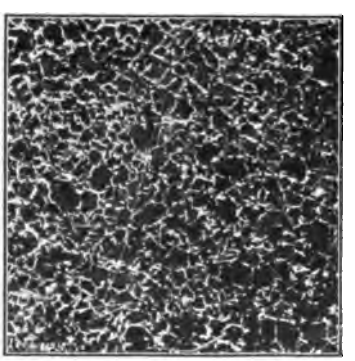
No. 21.



No. 22.

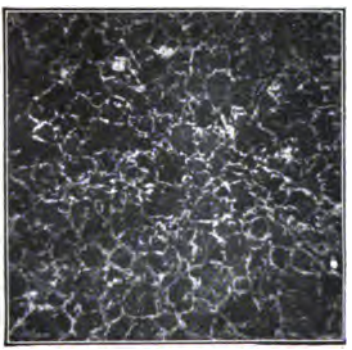


No. 23.



No. 24.

FIG. XV-D.



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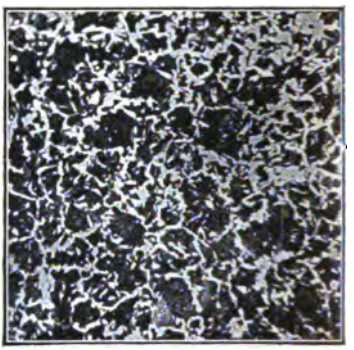

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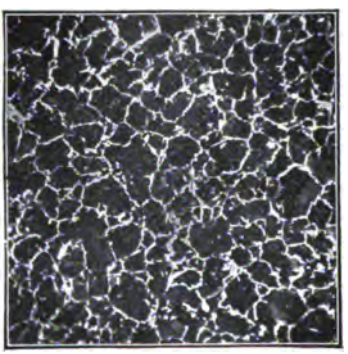

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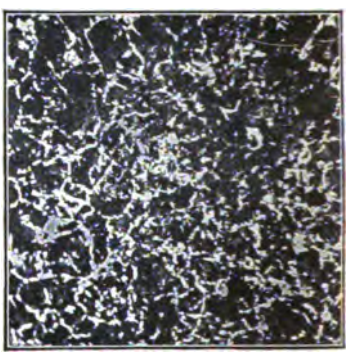

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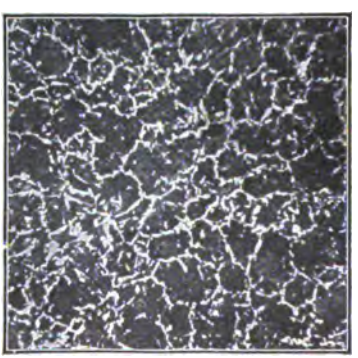

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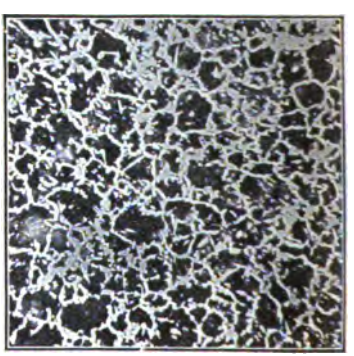
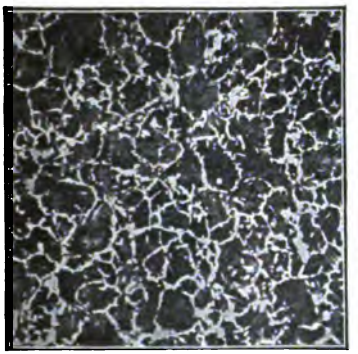
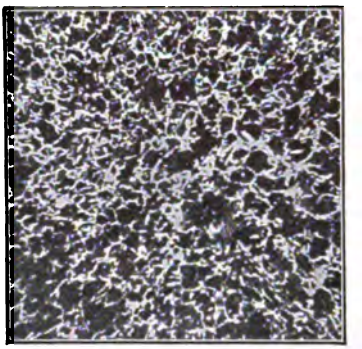


No. 30

FIG. XV-E.

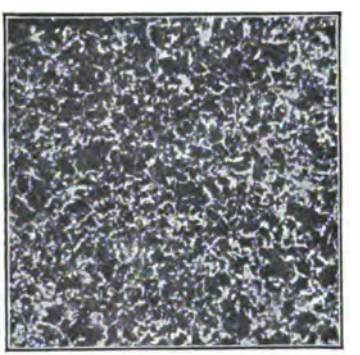


No. 31.

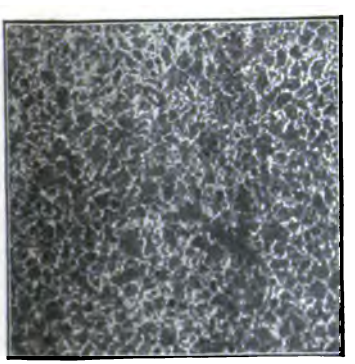


No. 32.

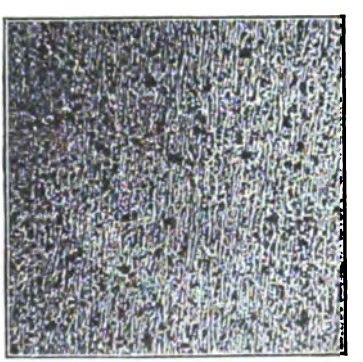
No. 33.



No. 34.



No. 35.



No. 36.

FIG. XV-F.

No. 37.

No. 38

No. 39.

No. 40.

No. 41.

No. 42.

No. 43.

No. 44.

No. 45.

FIG. XV-G.

the carbon content is increased the difference in temperature between these points grows less and less, until in the harder steels the variations are hardly beyond the limits of experimental error. Moreover, there are several elements beside carbon, like manganese, phosphorus, etc., which influence the location of the critical point, so that with two steels of the same carbon content, but with varying manganese, the upper critical point of one may be lower than the lower critical point of the other.

The three critical points in a cooling bar are distinguished as Ar_3, Ar_2, Ar_1, the point Ar_3 being the one at the highest temperature and Ar_1 at the lowest. In heating a bar the same three interruptions take place and the points are designated Ac_1, Ac_2, Ac_3, it being understood that in each case the lowest numerals Ac_1 and Ar_1 refer to the lowest temperatures, and the highest numerals Ac_3 and Ar_3 to the highest temperatures, and that points bearing the same exponent like Ac_1 and Ar_1 represent practically the same degree of temperature. In Fig. XV-A is shown a diagram which aims to represent the variations in the critical points for different steels. The data given by different experimenters vary considerably, but the heavy lines representing Ar_1, Ar_2 and Ar_3 are found by striking a sort of average from the available information. On each side of these heavy lines are shaded areas which represent the variations in the position of the critical point caused by differences in the content of manganese, phosphorus, etc. In the case of the soft steels the critical points are so far apart that the variations caused by these elements do not cause the maximum of one point to coincide with the minimum of the one just above, but as the content of carbon increases, the range between the highest and lowest critical points decreases, while the variations do not decrease, and as a consequence the maxima and minima run together so that they are indistinguishable.

The nature of the change that takes place at any one of these critical points is not known, but it is known that at each such point there is a great change in the micro-structure of the steel. It is known that the structure of the metal is quite different on either side of the critical points; that the forms, in which the iron and its alloyed constituents present themselves, change quite suddenly at certain definite points, and the structures found under certain well understood conditions are so characteristic that they form the basis of a science, but it is not known whether the heat liberated or ab-

sorbed at a critical point is due to the change from one structure to another, or whether both the change and the heat are due to some unknown molecular phenomena.

The next section will discuss the structures and forms which are best known and which must be studied to understand the effect of heat treatment.

SEC. XVj.—*Definitions of the different structures seen under the microscope.*—The microscopic examination of almost any piece of steel properly polished and etched will show that it is not entirely homogeneous, but that it is usually made up of at least two different forms of matter. It will not do to say that it is always made up of different substances, for it is generally agreed that some of these forms are allotropic,* the particular forms present in any one piece depending upon the way in which that piece has been heated and cooled. Considering all variations in heat treatment, the following forms will be encountered by the investigator: austenite, martensite, pearlite, cementite, ferrite, troostite and sorbite. Austenite is produced only by quenching steel containing more than 1.30 per cent. of carbon in ice water from above 1050° C. Its appearance is intended to be represented by the white portion of No. 1, Fig. XV-B, but this may be cementite in spite of the fact that the piece was steel containing 1.40 per cent. carbon, one-quarter of an inch thick, and was quenched in melting ice from a dazzling heat. Even under these conditions it is impossible to obtain a large quantity of austenite, since the tendency to revert to the next form is very strong when the proper temperature is reached. The theory of austenite, as well as of martensite, will be taken up in Section XVo. At about 1050° C. a change occurs, and in this grade of steel quenched below this point and above Ar_1 the second form, martensite, appears. This phase, together with a certain amount of cementite or of ferrite, depending on the carbon content, is found in carbon steels containing less than 1.30 per cent. of carbon quenched at any point above Ar_1, as will be shown in Table XV-M. Martensite is the constituent which confers hardness on steel and corresponds to the maximum hardness obtainable by

* The word "allotropic" is used by some of the metallographists to designate the character of the metallic aggregates. This is not strictly correct, since allotropy refers to unlike forms of the same element, while the different metallic aggregates found in microscopical investigations of masses of steel are not elements and are not of the same composition. The term "phase" was introduced by Gibb and is used later in this discussion.

carbon alone. It may be compared to a sugar solution which is more or less sweet according to the proportion of sugar present. Martensite may be easily recognized by its appearance, shown in Fig. XV-B No. 2. At the upper critical point Ar_3, the conditions become more favorable for the production of cementite and ferrite, and variable amounts of one or the other are formed, depending on the carbon content; at the second critical point, Ar_2, no radical change is noticeable, the only effect being an increase in the amount of cementite or ferrite, but at the lower critical point, Ar_1, the martensite disappears, and in steels cooled slowly to below this temperature the structure is composed entirely of ferrite, or entirely of pearlite, or of pearlite mixed with ferrite or cementite. Ferrite is iron free from carbon and forms almost the whole of a low carbon steel, while cementite is considered to be a compound of iron and carbon denoted by the formula Fe_3C, the carbon of this form being known as cement carbon. Pearlite is formed by the structural union of ferrite and cementite in definite proportions, not being a compound, but simply an intimate mixture. It appears in two forms, granular and lamellar, the former being seen in steel which has been worked or reheated to a low heat, while the latter is found only in steel which has been cooled slowly through the critical range. It is to the lamellar variety that its name is due, the structure by oblique light giving an effect like mother of pearl. In addition to these common forms there are two others, troostite and sorbite, of which little is known at present. As steel cools through the critical range, the transition from martensite to one of the forms contained in unhardened steel is not abrupt, but appears to be in two steps. Thus by quenching during this critical change a new condition will be obtained—troostite—and if this quenching takes place at the end of the critical range in cooling, a second effect is noticed, which is called sorbite. Quenching in lead, or reheating quenched steel to a purple tint may also produce sorbite, and Osmond states that when small pieces are cooled in air the chilling is sufficiently rapid to prevent the complete transformation into ferrite and cementite, some sorbite being formed. Thus austenite, martensite and troostite are found only in steel quenched at or above the critical range, while ferrite, cementite, pearlite and sorbite, are characteristic of unhardened steel. It is difficult to develop troostite and sorbite in the process of etching in such a way that they will be clearly visible under the microscope, and it has

already been stated that the conditions of their existence are uncertain, so that for practical purposes these two forms may be neglected until their properties have been further studied, and since the conditions under which austenite is formed are never realized in practice, this also may be passed by. Ferrite and cementite present very nearly the same appearance, but they never occur together, and as they differ very much in hardness it is easy to distinguish them, for ferrite is pure iron and if the point of a needle is drawn across it the surface will be easily scratched, while cementite is a compound of carbon and iron and the point will make very little impression. It is generally admitted that ferrite is structureless even under the highest powers of the microscope.

Pearlite is an "eutectic alloy," a term which may possibly not be familiar to all readers. An eutectic alloy is formed by the simultaneous crystallization of different metals in a liquid mixture, as for example a mixture of copper and silver. These metals form an alloy in the proportions of 72% silver and 28% copper at a temperature of 770° C. (1418° F.), and if a melted mixture of these two metals contain any different proportion than this, and if it be allowed to cool, the element in excess of this proportion crystallizes out, the crystals remaining uniformly distributed throughout the molten mass. When the critical point of 770° C. is reached, the alloy of 72 silver and 28 copper becomes solid, and entrains the innumerable crystals of the excess element which have separated from the mother liquid. A little consideration will show that under the microscope the element solidifying first and the eutectic alloy will occupy areas exactly proportional to the original constitution.

In steel at high temperatures the same conditions exist as in the mass of silver and copper just described, save that the elements are in what is called "solid solution," martensite at the lowest critical point going through a transition into ferrite and cementite. The element in excess separates by itself, and when the proper relation has been established the ferrite and cementite crystallize together in most intimate mixture to form pearlite. As stated previously, the excess of cementite or ferrite begins to form by itself at the upper critical point, a small amount being found in steel quenched just below this, and at the second point this amount is increased, but this excess is always small except in the case of low carbon steel.

The foregoing argument may be summarized as stated by Sauveur:

(1) All unhardened steels are composed of pearlite alone, or of pearlite associated with ferrite or cementite.

(2) Without taking into consideration austenite and troostite, hardened steel is composed of martensite alone, or of martensite associated with ferrite or cementite.

(3) Ferrite and cementite cannot exist together in the same piece of steel.

(4) The presence of the lamellar variety of pearlite is almost certain proof that the steel has been annealed.

Following the proposition that ferrite is iron free from carbon and that cementite is a compound represented by the formula, Fe_3C, it is evident that in very low steels, say ranging from .02-.10 carbon, the structure will be almost entirely ferrite, and that in steel of 2.00 per cent. carbon there will be an excess of cementite. There will therefore be one point of carbon content at which the component ferrite and cementite will both be satisfied, which is to say that the original proportion will be that of the eutectic alloy. This occurs in a pure steel containing about .80 per cent. of carbon, the micro-structure of this grade showing no ferrite or cementite.

Late investigations seem to prove that in hypereutectic steels, that is, those containing more than .89 per cent. of carbon, the upper critical point, A_3, follows the curve, SE, in Fig. XV-H. This is the point at which cementite begins to form and, according to Howe and Roberts-Austen, progressively separates out within the martensite in cooling and forms a network whose coarseness is proportional to the temperature to which the steel has been heated. No break in the cooling curve has been noticed, but the first appearance of cementite is considered to mark the point, Ar_3, while Ar_2 and Ar_1 are as given in diagram Fig. XV-A.

Tables taken from Prof. Sauveur give results as shown in Tables XV-L and XV-M, the numerals being intended to represent per cent. of volume, since if a body containing an infinite number of particles, uniformly distributed, is cut by a plane, the ratio of the sum of the small areas to the total area is equal to the ratio of the volume of the small particles to the total volume. Theoretically, of course, this is not true of a mass of steel, but for practical purposes it is correct.

The different photographs in Fig. XV-B represent the appearance of steels of different carbon content. No. 3 is a steel containing 1.39 per cent. of carbon and is from a bar in the condition in which it left the rolls. It shows a pearlite grain surrounded by walls of cementite. Nos. 4 and 5 represent lamellar and granular

TABLE XV-L.

Theoretical Micro-Structure of Carbon Steels.

Carbon per cent.	Pearlite.	Fe.	Cem.
0	0	100	0
.10	12	88	0
.40	50	50	0
.70	87	13	0
.80	100	0	0
1.00	97	0	3
1.20	93	0	7
2.50	71	0	29

TABLE XV-M.

Micro-Structural Composition of some Quenched Carbon Steels.

Carbon, per cent.	Quenched above Ar_3			Quenched between Ar_3 and Ar_2.			Quenched between Ar_3 and Ar_1.			Quenched below Ar_1 or slowly cooled		
	Mart.	Fer.	Cem.	Mart	Fer.	Cem.	Mart.	Fer.	Cem.	Pearl.	Fer.	Cem.
0.09	77	23	0	27	73	0	11	89	0	10	90	0
	Quenched above Ar_3.											
	Martensite.		Ferrite.		Cementite.							
0.21	100		0		0		31	69	0	23	77	0
0.85	100		0		0		56	44	0	50	50	0
	Quenched above Ar_1.											
	Martensite.		Ferrite.		Cementite.							
0.80												
1 20	100		0		0					100	0	0
2 50	94		0		6					92	0	8
	80		0		20					77	0	23

pearlite respectively. No. 6 is a steel containing .67 per cent. of carbon, the appearance of which is similar to No. 3, but there is really quite a difference, in that there is not a sufficient amount of carbon to form the eutectic alloy. Consequently there is an excess of ferrite and this forms the walls, whereas when the carbon ex-

ceeds .89 per cent. there is an excess of cementite, which therefore forms the walls. Nos. 7 and 8 contain very little carbon, No. 8 being especially soft, showing almost no pearlite.

Index of Micro-Photographs, Figs. XV-B to G.

No.		Magnification. Diameters.
1	Austenite	900
2	Martensite	175
3	Pearlite with cementite walls C=1.39	75
4	Lamellar pearlite	900
5	Granular pearlite	900
6	Pearlite with ferrite walls C=0.67	75
7	Mild steel C=0.20 showing ferrite and pearlite	75
8	Ferrite C=0.03	75
9	Cold worked steel showing lines of flow and in center actual rupture	30
10	Nickel steel roll, fracture in relief	1
11	Same steel as No. 10, polished and etched	50
12	Nickel steel roll shown in No. 10, annealed at 800° C	50
13	Small piece of same nickel steel roll annealed three times at 850°, 800°, 750° C.	50
14	Special high carbon steel, unannealed	50
15	Special high carbon steel, annealed	50
16	Carbon steel casting, unannealed	20
17	Same steel as No. 16, annealed	50
18	Same steel as No. 16, annealed twice	50
19	75-lb. T rail, center of head; broken in service	46
20	75-lb. T rail, center of head; broken in service	46
21	85-lb. T rail, center of head; broken on drop test	46
22	100-lb. T rail, center of head; finished at 1000° C	46
23	85-lb. T rail, center of head; "hot rolled"	46
	This rail was one of two from the same ingot rolled under different conditions. See Section XVe, Par. 1 and 2.	
24	85-lb. T rail, center of head; "cold rolled." See No. 23	46
25	107-lb. girder rail, Sec. 228, P. S. Co	44
26	107-lb. girder rail, Sec. 228, P. S. Co	46
27	90-lb. girder rail, Sec. 200, P. S. Co	46
28	90-lb. girder rail, Sec. 200, P. S. Co	46
29	70-lb. T rail, Sec. 237, P. S. Co., center of head	46
30	70-lb. T rail, Sec. 237, near surface	46
31	M. S. Co. 100-lb. T rail, center of head	46
32	M. S. Co. 100-lb. T rail, near surface	46
33	M. S. Co. 85-lb T rail, near surface	46
34	M. S. Co. 85-lb. T rail, "hot rolled." See No. 23	46
35	M. S. Co. 85-lb. T rail, near surface, "cold rolled." See No. 23	46
36	Bessemer steel, C=0.45. Finished at 490° to show effect of cold rolling	50
37	Ingot structure, C=0.06	20
38	Center of 1" round, C=0.06	75
39	Near surface of same piece as No. 38, showing loss of carbon by heating	75
40	Ingot structure, C=0.47	20
41	Bloom 8"x8", rolled from 32"x38" ingot; C=.40	75
42	Billet 2"x2" hammered from bloom shown in No. 41	75
43	Section of a finished angle	75
44	Ingot structure, C=1.00	20
45	1" round rolled from ingot shown in No. 44	50

SEC. XVk.—*Effect of work on the structure of soft steel and forging steel.*—Steel as usually cast, cooling slowly from the liquid state with no work done upon it, forms in crystals and shows in general the same structure throughout. The outer skin has a structure different from the rest of the mass, as it cools quickly and is under heavy strains as long as any of the metal is hot, and there is also an area of abnormal crystallization at the top of the ingot due to segregation, but the greater part of an ingot is of the same general crystalline character. Rolling tends to break up this grain and prevent further growth during the process, but immediately after cessation of work the formation of grains begins and continues until the metal has cooled to the lower critical point. Hence it is evident that the lower the temperature to which steel is worked the more broken up the structure will be, but on the other hand if the rolling be continued below the critical point, the effect of cold work will be shown and strains will be set up which will make the piece unfit for use without annealing. Consequently it is necessary to stop the work somewhat above the critical point and in practice with large pieces it is customary to finish some 150° C. to 200° C. above this point, since the metal becomes so stiff at the lower temperature that the wear and tear on the rolls is excessive.

In blooms, billets and such hard steels as are to be reheated for hardening, the need of an extremely low finishing temperature is not so evident. If the grain be reasonably fine, the metal is solid and dense, and the crystallization of the steel when put in service will be determined by the final heat treatment. This will be taken up more in detail in Section XVm. It would appear that the smaller the piece the finer the grain, and this arises partly from the necessity of finishing a large piece while the center is still hot and partly from the slower rate of cooling of the large piece. In No. 37, Fig. XV-G, is shown the micro-structure of a low-carbon ingot magnified 20 diameters and in Nos. 38 and 39 the same grade of steel rolled into 1″ rounds and magnified 75 diameters. These last two are the center and outside respectively of the same piece and show the effect of a high temperature in burning the carbon of the steel near the surface. The dark element in No. 38 is pearlite, the light is ferrite. It will be noticed that very little pearlite is shown in No. 39. This is in accordance with the explanation in Section XVm, where it is shown that if the carbon were partly burned away it would leave just so much less cementite

to mix with the ferrite to form pearlite, and consequently leave more ferrite free. In No. 40 is shown the structure of an ingot containing 0.47 per cent. of carbon magnified 20 diameters. No. 41 gives the structure of an 8" bloom rolled from a 32"x38" ingot, and No. 42 a test from the same bloom hammered to a piece 2" square. These last two are magnified 75 diameters, and it should be noted that the areas of the ingot structure shown in the photographs are to the areas of the finished pieces as one to fourteen.

Figs. 44 and 45 show the structure of a steel containing about one per cent. of carbon before and after rolling, the first being a section from a 16"x20" ingot, the latter a section from a piece 1" in diameter cooled on the hot bed. It will be seen that the grain is well broken up without any sign of cold work, and the bar is consequently in very good condition for the hardening and tempering to which such hard steels are usually subjected. This bar was taken at random from the hot bed at Steelton.

If steel is worked below the critical point, strains are developed which injure the metal and may even rupture it. In No. 9, Fig. XV-B, is shown a piece of forging steel magnified 30 diameters. This illustrates the distortion of cold work, and the black line in the middle of the print is a crack where the tension became greater than the cohesion of the metal.

SEC. XVI.—*Effect of work upon the structure of rails.*—Nos. 19 and 20, in Fig. XV-D, show the micro-structure of two rails which broke in service. No data are available as to how long they had been in use, but it is probable that it was only a short time. No. 21 is an 85-lb. T rail, which broke under the drop test. These three fractures, as well as all the other photographs, are selected not as exceptional, but as representative of what will usually be found under similar conditions. Fig. 22 is made from a heavy rail section finished at a temperature of 1000° C., and it will be noticed that its appearance is almost if not quite the same as that of Nos. 19, 20 and 21. In Nos. 23, 24, 34 and 35 are shown the results of some experiments performed by Mr. S. S. Martin at the works of the Maryland Steel Company at Sparrow's Point. An ingot was rolled into blooms and two adjacent blooms were rolled into rails without further heating, the first being held before rolling in order to allow it to cool so that all work should be done at as low a temperature as possible, without, of course, reaching the lower critical point, while the second was rolled as quickly as possible through all the

passes except the last, but was then held at the finishing pass 1¾ minutes, the result being that both pieces went through the finishing pass at the same temperature, which was about 750° C. I will designate as the "hot-rolled rail" the one which was rolled rapidly, but which was cooled down just before the finishing pass, and as the "cold-rolled rail" the one which was rolled at a lower temperature during the whole operation.

No. 34 represents the micro-structure of a portion of the hot rolled rail at a place very near the surface and No. 35 the structure of the cold-rolled rail at a similar place. It is evident that a superficial examination of photographs, without any knowledge of certain fundamental conditions, might lead to the conclusion that the two methods of rolling gave identical results, but the testimony of Nos. 23 and 24 proves quite the opposite. No. 23 is from the center of the head of the hot-rolled rail and No. 24 from the center of the cold-rolled rail, and it is clear that there is a radical and fundamental difference in the results, the reason for which is perfectly clear.

The finishing pass in almost every set of rolls does very little work, for it is unusual to have over ten per cent. of reduction upon the piece, oftentimes there being much less, while in all other passes, save one regulating the height, it is usual to have from twice to three times as much. Consequently the effect of the last pass does not penetrate to any great depth. Such a penetration is necessary if the grain is to be broken up, for the head of a heavy rail offers a thicker mass of metal than is found in almost any other structural shape, and the very fact that it is considered necessary to hold a rail before finishing proves that the grain needs to be broken. If the rail is at a sufficiently low temperature the grain will not grow coarser as the rail stands, and the rail might as well be finished at once; but if it is at a high temperature and the grain is coarse, then it will do no good to hold it before the last pass, or to shower it with water, for this will merely perpetuate the coarse crystallization that exists. The holding of the rail therefore before the last pass is a delusion; it gives a lower finishing temperature and a low shrinkage, and it renders possible a very nice looking photograph from a piece of the outside skin, but it does not give any of the fundamental good qualities which should accompany such a finishing temperature, and which will accompany it if the temperature of the finishing pass is a true exponent of the rolling conditions. The

attempt to estimate the structure of the rail from the amount of shrinkage is simply putting the cart before the horse; it is much like the practice in vogue a few years ago of rolling octagon spring steel and then defacing the bar by hitting it with a hammer to make it resemble the bars turned out by the tilting hammer. This tilting consisted in a rapid succession of blows continued during the cooling of the piece until a very low temperature was reached, and by this means the crystalline structure was rendered very fine and the steel was in the very best condition. The rolls did not finish the bar as cold, nor did the effect of rolling penetrate as thoroughly as the blow of the hammer, and this lack could hardly be atoned for by duplicating an incidental accompanying condition.

There will always be some difference between the structure of the center of the head of the rail and the portion near the surface, but if the rail is rolled at a proper temperature during the passes when considerable work is put upon the piece, this difference will not be serious. No. 25, in Fig. XV-E, shows the center of the head of a girder or tram rail weighing 107 pounds per yard, and No. 26 shows the surface of the head. No. 27 shows the center of the head of a 90-pound girder rail and No. 28 the surface. No. 29 is the center of a 70-pound T rail and No. 30 the surface. All these were rolled at Steelton on regular orders and it will be noted that while there is a difference, the structure of the center is very good.

Fig. XV-F shows the structure of T rails rolled at Sparrow's Point at the works of the Maryland Steel Company and represents the best modern practice. No. 31 is the center of a 100-pound T rail and No. 32 the surface; No. 33 the center of an 85-pound T rails, these structures representing the regular practice at the works. Nos. 34 and 35 have already been discussed as hot-rolled and cold-rolled rails. No. 36 represents the structure of a small test bar of rail steel which was rolled for the purpose of this experiment as cold as the strength of the rolls would allow, the finishing temperature being 490° C. (915° F.), which is considerably below the critical point, as shown by the lines of work appearing in the photograph. This evidently is the finest structure obtainable, and it may be used as a standard by which to estimate the condition of the other pieces. All the photographs in this rail steel series are cross-sections that are magnified forty-six diameters.

SEC. XVIII.—*Effect of heat treatment upon the structure of cast-*

ings.—It has been proven by many investigators and is generally acknowledged that in heating steel through the lowest critical point the crystalline structure is obliterated, the metal assuming the finest condition of which it is capable. Above this point the size of the grain increases with the temperature. There is a difference of opinion as to whether the increase in size takes place during the heating or at the moment when cooling begins, but it is unnecessary to determine this question, the general proposition being true that the higher a piece of steel is heated above this point the larger the grain becomes.

At the corresponding point in cooling, the structure ceases to change, except in very soft steel, as shown by Stead, and any size of grain is retained and cannot be changed by heat treatment below this point. There is, however, a change from hardening to cement carbon, which may take place at comparatively low temperatures. This is the principle on which the tempering of steel is founded, quite a definite amount being changed at temperatures which are represented approximately by the color of the bar. Cement carbon is that form which confers the softest possible condition and greatest ductility, while hardening carbon gives the condition of greatest hardness. Hence the temper is drawn by every rise in temperature.

At the lowest critical point the change from cement to hardening carbon takes place almost instantly, all carbon above this temperature being of the hardening variety, but the reverse change in cooling appears to require a certain length of time. This is the explanation of hardening by quenching, the more rapidly the steel is cooled through this point, the less being the chance of the carbon to change its state. A sudden cooling in ice water prevents any change, while annealing is effective only in proportion as the time of exposure to this temperature was long or short. Since fine structure and cement carbon are the principal factors of toughness and ductility, both of which are the aim in annealing, it would seem that the best method of tempering would be to heat to the lowest critical point and not higher, and quench from this heat and subsequently draw the temper. Similarly the best way of annealing, since the reverse change takes place several degrees below this, would be to cool at once to just above this lower point and allow several hours for the metal to cool past the critical tempera-

ture, and long enough from this point to the cold state to prevent the setting up of strains from too rapid cooling.

Practically, however, it seems to be necessary to heat considerably above the lowest critical temperature in order to insure the thorough breaking up of the cell walls to allow the enveloping form to permeate the grain. This arises from the fact that the changes by which ferrite is formed attain their maximum effect only when the metal is subjected to a range of temperature which includes the three critical points. When steel cools slowly a certain amount of ferrite forms at the upper point, Ar_3, an additional amount at the second point, Ar_2, while the principal change occurs at the lowest point, Ar_1. Thus if the metal be considered as a solid solution, it may be said that crystallization takes place at the upper point, the solution of martensite becoming more concentrated. When the steel is heated, as in the case of annealing, the reverse phenomenon takes place, for at the lowest point the grain is broken up, the pearlite becoming martensite, somewhat diluted by the portion of ferrite which it takes up. If now the piece be cooled slowly without further heating, the resulting structure will be quite different from the original. The size of the grains will be much smaller and the piece will therefore be in much better physical condition, but there will still remain room for improvement, for throughout the mass will be found a certain proportion of ferrite, corresponding to the amount which, as already explained, is transformed at the higher temperatures of Ar_2 and Ar_3.

In order therefore to thoroughly disseminate the ferrite and encourage to the greatest extent the formation of martensite, it is necessary to heat to the upper critical point Ac_3. This high temperature, however, gives rise to a somewhat larger grain than if the lower critical point, Ac_1, had not been exceeded, so that while there is a gain in the extent of the transformation, the grain of the resulting steel is coarser and there is consequently a loss in strength. The best result is obtained by combining the two methods, the steel being first heated to the upper critical point, Ac_3, and allowed to cool slowly, by which complete transformation is effected, and then reheated just above the lower critical point, Ac_1, by which the grain is rendered fine and all strains obliterated. In case two heatings are out of the question, it is generally better to heat to the upper critical point, as it is preferable to have a slightly larger grain with a fine division of the microscopic forms, than to have a piece

of metal of somewhat finer grain but much less homogeneous. Considerable care must be exercised in heating pieces which are not to be machined after treatment, since at a high temperature the carbon near the surface of steel is burned out to an appreciable depth by the action of the flame, unless the metal is protected in some way from oxidation. An effect of this kind may be noticed under the microscope with little difficulty. If the carbon has been driven off it follows that there is less cementite left to combine with ferrite to form pearlite when the metal is cooling through the critical point. Consequently there will be less pearlite formed in the oxidized surface than in the remainder of the piece. This effect is shown in Nos. 38 and 39, these being the center and the outside respectively of a soft steel bar.

In No. 11, Fig. XV-C, is shown a large pearlite grain surrounded by a thick wall of ferrite. This represents the micro-structure of a 28-inch steel roll casting containing .25 per cent. carbon and 3.5 per cent. nickel, which was put in service unannealed and broke within a few hours. In No. 10 is shown the fracture in natural size, and the photograph was made from the broken specimen without any polishing or other treatment. It is a striking illustration of intergranular weakness, the lines of rupture following almost entirely the ferrite envelope and leaving the individual grains intact. No. 12 shows the micro-structure of this broken roll after one annealing at 800°, and notwithstanding the exceedingly coarse structure of the original casting the annealed micro-structure is quite fine and shows a grain outline very much broken up. It is probable that a second annealing would have almost obliterated the crystallization, and it would have been interesting to carry this on for several more heat treatments, but as this was impracticable a piece was cut off and heated successively to 850°, 800° and 750° Centigrade and allowed to cool slowly with a complete destruction of crystallization as shown in No. 13.

It should be noted that No. 11 and No. 12 are results obtained with full size pieces, and not with small tests, as is too often the case, under which circumstances the results are not always comparable with the effect on a large piece. The two pieces were taken from the same relative positions and represent, it is believed, the structure of the roll. The casting conditions, so far as could be determined, were normal. The annealing was effected at 800° C. as registered by the pyrometer, it being necessary to consider that

this does not always represent the temperature exactly unless the "invisible" condition is obtained.

No. 16 represents the micro-structure of a steel casting unannealed, magnified 20 diameters. It is almost impossible to give an idea of the structure in a small photograph, but the illustration shows parts of three grains, and like all the other reproductions, is typical. No. 17 shows the same casting after annealing. The picture is not all it should be, but by careful examination a remarkably small grain may be distinguished; the areas of pearlite and ferrite are indicative of an insufficient breaking up of the microscopic forms. No. 18 represents the casting after a second annealing. No. 14 and No. 15 show the structure before and after annealing of a special high carbon casting used in railroad work where ability to withstand shock is of prime importance.

As stated in Section XVi, the second critical point is characterized by a loss of the magnetic properties in heating; this point is very easily determined by using an electro magnet, the wires of which are connected with a sensitive galvanometer. The act of moving the magnet into and away from contact with the metal moves the needle of the galvanometer as long as the metal is magnetic. It would seem as if this should be a good point to agree upon as the temperature to which castings shall be heated for annealing. Sufficient data are not available to state positively that such treatment would give the best results possible, but it seems quite certain that treatment on this line would give good structure and be a great improvement on most of the haphazard methods now in use.

SEC. XVn.—*Effect of heat treatment on the structure of rolled material.*—In order to determine the effect of heat treatment on the structure of rolled material, tests were taken from finished angles, the general method of procedure being as follows:

A piece five feet long was sheared from the angle and cut into five equal lengths. An ordinary test bar was taken from one of the legs of each piece in the same relative place and numbered from 1 to 5. From each of the extremes 1 and 5 a section was cut for the microscope and the bars pulled in the testing machine to prove that the piece was homogeneous. The bars, 2, 3 and 4, were treated in a muffle heated by an electric coil at temperatures varying from 625° C. to 890° C., the temperature in all experiments being taken by a Le Chatelier pyrometer. No attempt was made to heat

the pieces quickly, as it was intended to work under normal conditions, the operation usually occupying from one to three hours. The bars were held at the high temperature only long enough to insure uniform heating and then cooled for several hours to about 350° C. A longer annealing would probably have given slightly different physical results on account of the more nearly perfect elimination of strains and transformation to cement carbon, but the difference would have been slight, and as the object was to determine the effect of heat on the structure it was unnecessary to consider this phase of the problem.

Small sections were cut from the treated pieces, as well as from the untreated, and were polished and etched. They were invariably taken from the same relative position and etched on the surface representing the cross section of the angle. A great majority of these specimens when examined under the microscope showed well defined structures similar to those exhibited in Nos. 8 and 43. The orientation was apparently the same in both the treated and the untreated bars, and the size of the grains did not appear to be affected by the treatment, although bars from different heats showed considerable variation. It would therefore seem probable that as finely divided a grain can be produced by rolling as by any of the usual annealing processes, although there is room for further investigation on this point.

SEC. XVo.—*Theories regarding the structure of steel.*—There are several theories now before the scientific world to account for the hardening and the magnetic transformations in steel and the phenomena of the so-called critical points. It would be better perhaps to call them hypotheses, as they are in each case offered tentatively and as lines of thought on which to base experimental research. It is beyond the province of this book to enter into a full discussion of these various conceptions, but it may be well to give a brief summary of the most prominent.

The carbon theory considers that the effect of hardening is due entirely to a change in the carbon contained in the steel. In common with the other theories, it supposes that at temperatures below the critical point the carbon is in the state of cement carbon, combined with iron in the proportion Fe_3C. At the lower critical point a change in carbon is supposed to occur, and since from temperatures above this point carbon steels are hardened by sudden cooling, the advocates of this theory have devised the name "hardening

carbon." The cause of evolution of heat at this point in cooling is considered to be the change from hardening to cement carbon, but no satisfactory explanation is given by this theory for the changes at the second and third critical points.

The allotropic theory holds that the iron of the steel is in different allotropic forms between the different critical points, and that below the second critical point the iron exists as *alpha* iron, but at this point *beta* iron is formed, and at the upper *gamma*, the carbon being diffused in the iron. The cause of the evolution of heat is explained by the change from *gamma* to *beta* iron at Ar_3, from *beta* to *alpha* at Ar_2, while at Ar_1 the carbon combines with *alpha* iron to form Fe_3C. The retention of a hard allotropic state of iron, this retention being helped by the presence of carbon, is considered to be the cause of hardening.

The carbo-allotropic theory is similar to the allotropic theory, except that hardening is supposed to be due to the retention by sudden cooling of a hard carbide of iron.

The Phase Doctrine. Prof. Bakhuis-Roozeboom explains* the detail of the Phase Doctrine, a phase being defined as a mass chemically or physically homogeneous, or as a mass of uniform concentration. Thus he states that a phase may be liquid or solid, may be an element or a compound, or a homogeneous mixture of variable concentration. Carbon, *alpha, beta* and *gamma* iron, liquid solutions, solid solutions of carbon in *gamma* iron or martensite, cementite and ferrite are all phases, while pearlite is a conglomerate of phases. He gives a diagram shown in Fig. XV-H, which is intended to show the critical changes of alloys of iron and carbon containing different percentages of carbon at different temperatures.

From this it may be seen that the area, PSTN, represents the structure of slowly cooled steels containing less than .89 per cent. of carbon, and SKLT the structure of high carbon steels cooled slowly. MOSP is the region between A_1 and A_2, showing *alpha* iron, while GOM is that between A_2 and A_3, *beta* iron. Above GOS, which is the line A_3 in Fig. XV-A, the iron is in the phase *gamma*, the micro-structure being 100% martensite. As shown by the curve, SE, the higher the carbon in the steel the higher the heat needed to prevent the separation of cementite. Thus *m* in a 1.00 C steel is the temperature necessary to hold in solution the excess

* *Zeitschrift fur Physikalische Chemie*, Vol. XXXIV, 1900. I. and S. Inst., September, 1900.

of cementite. At about 1050° C., however, cementite as such disappears even in high carbon steels and the carbon is considered as being in solution in *gamma* iron. This is the point above which it is necessary to heat in order to obtain austenite, from which it is argued that austenite is carbon dissolved in *gamma* iron.

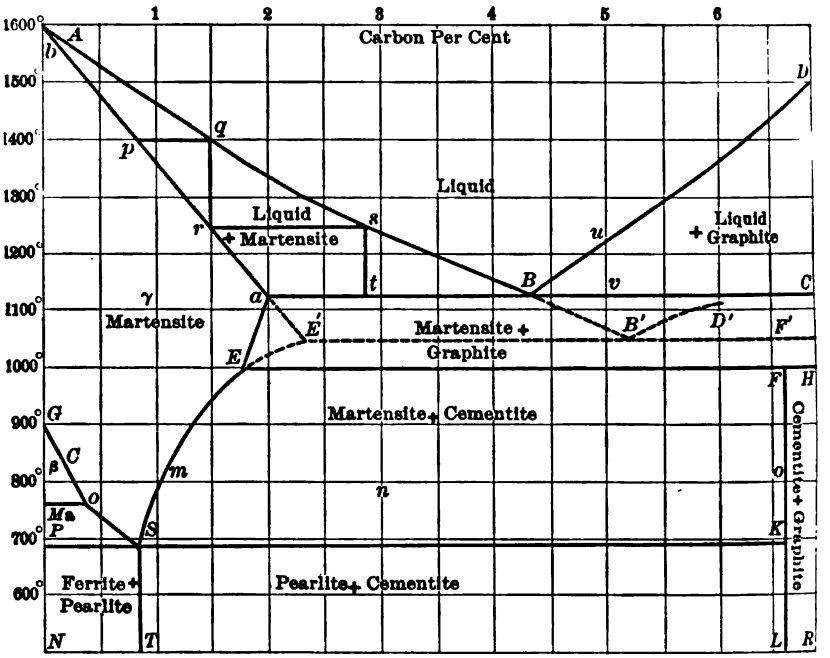


FIG. XV-H.—GRAPHICAL REPRESENTATION OF THE PHASE DOCTRINE.

Martensite is considered as a solution of Fe_3C in allotropic iron, being a saturated solution in steel containing about .89 per cent. carbon.

Prof. Arnold has disputed the allotropic theory in several articles and has evolved an hypothesis of his own which he calls the "sub-carbide theory," on the supposition that hardening is due to the retention of a hard sub-carbide of iron $Fe_{24}C$.

These theories will be found thoroughly considered in the volumes of the Iron and Steel Institute of the past few years. Enough is given here to show the variety of ideas, all of which have their strong and their weak points.

CHAPTER XVI.

THE HISTORY AND SHAPE OF THE TEST-PIECE.

SECTION XVIa.—*Differences between the surface and the interior.*—The first question in the inspection of steel is the manner in which the test-piece shall be taken. In former days it was the custom to plane or turn a piece to a standard size, and this method is still used in steel castings, for it is impossible to cast a bar of sufficiently accurate section, and it is also used in the case of forgings when it is deemed advisable to carve a piece from the finished material. In other work the test is either a part of the finished bar, as in small rounds and flats, or is cut from the member, as in angles, channels, etc. A sufficient length is taken to allow about 10 inches between jaws, and the readings are on an 8-inch length defined by marks of a center-punch.

A machined piece is generally inferior to a bar as it leaves the rolls. In tests made by the United States Government* in 1885, the machine was not powerful enough to pull a seven-eighth inch round, so that rods of this size were turned down to three-quarter inch in diameter. The comparative results are given in Table XVI-A, the figures in each case representing the average of 14 heats. The pieces cut from the seven-eighth inch bar are inferior

TABLE XVI-A.

Properties of ¾-inch Rounds in their Natural State, and ⅞-inch Rounds of the Same Heats Turned Down to ¾-inch.

Condition of bar.	Ult. strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
¾ inch natural,	66764	27.53	42.7
⅞ inch turned to ¾ inch,	65088	25.30	42.0

* *Report of the Naval Advisory Board*; 1885, pp. 81, 82.

to the three-quarter inch tests, although the larger bar should give the better elongation. The inferiority is due to the removal of the best part of the piece in turning. This phenomenon is more marked in larger sizes, as shown by Table XVI-B, which gives the results on bars cut from forged bridge-pins.

TABLE XVI-B.

Test-Pieces ¾-inch in Diameter, cut from Forged Rounds.

Size of Ingot, 18x20 inches. Pennsylvania Steel Company, 1893.

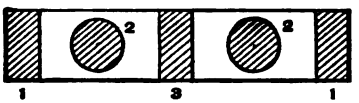
Diameter of forged round.	Place from which test was taken.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
8 in.	At a depth of 1 inch from outside.	62720	32870	21.50	40.4	52.4
	At a depth of 2 inches from outside.	58100	29170	22.25	37.5	50.2
	The central axis.	58100	31490	20.25	34.1	54.2
10 in.	At a depth of 1 inch from outside.	66070	37080	19.50	33.9	56.1
	At a depth of 2½ inches from outside.	62750	35670	18.00	32.7	56.8
	The central axis.	60900	32140	19.50	28.8	52.8
Preliminary test of same heat from 6 in. ingot		63980	42250	26.25	41.7	66.1

SEC. XVIb.—*Strips cut from eye-bar flats.*—Similar differences will be found if test-pieces be cut from different parts of eye-bars, as illustrated by Table XVI-C. These results display considerable uniformity in the higher strength of the bars from the large ingot, but the number of specimens is not sufficient to establish the fact. Such a comparison is often invalidated by unknown factors, for if the test-bar be finished hot and the "flat" cold, the relation may be reversed. Table XVI-D shows the comparative results on nine heats of steel, and will illustrate how the preliminary test may differ from the finished bar in individual cases, while the average of the two is the same.

SEC. XVIc.—*Longitudinal and transverse test-pieces from plates.*—Differences may also be found between strips cut lengthwise from a plate and those cut crosswise. Mr. A. E. Hunt states that "in plates up to 30 inches wide there is, ordinarily, a difference of 10 per cent. in tensile strength, and up to 20 or 25 per cent. in ductility in favor of pieces cut with the grain. In wide

TABLE XVI-C.

Test-Pieces from Rolled Flats, and from ¾-inch Rounds of the Same Heats Rolled from a 14-inch Square Ingot.



1, 1—edge of bar; 2, 2—¾-inch rounds cut on a machine; 3—center of bar; 4—¾-inch round rolled from an ingot.

Number of group.	Limits of ultimate strength in group, of the ¾-inch round rolled from the ingot; pounds per square inch.	Number of heats in group.	Place from which test was taken; see head of table.	Ult. strength pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
I	55000 to 60000	2	1	57450	35085	61.1	28.50	51.97
			2	57095	31575	55.3	27.37	54.43
			3	56990	33195	58.2	25.13	48.99
			4	59468	43489	73.1	27.90	63.01
II	60000 to 65000	6	1	61586	36677	59.6	26.78	48.60
			2	60712	34572	56.9	26.82	53.22
			3	60870	34512	57.2	25.06	44.36
			4	64461	42872	66.1	26.17	50.67
III	70000 to 75000	3	1	69816	39068	61.2	26.72	51.02
			2	64420	35940	55.8	27.37	54.43
			3	62955	37892	60.2	26.28	46.69
			4	70541	47045	66.7	24.51	49.96

plates the difference is not as marked, on account of the effect of cross-rolling."

I believe these differences will be less in plates rolled from a slab than in those made directly from an ingot. In any event, plates can be made by the first method which exhibit practically the same properties in both directions. This will be shown by Table XVI-E, which gives the averages of 100 plates rolled from Pennsylvania Steel Company slabs. The total number of plates was 104; of these, one was rejected on account of gauge, and three on account of tensile strength. No plate was thrown out for deficient ductility, although an elongation of 25 per cent. in 8 inches was required in both longitudinal and transverse strips, both these tests being made on each separate plate. The thickness varied from one-half inch to three-quarter inch, and the width from 52 inches to 87 inches. The steel was basic open-hearth, with an average composition as follows: Carbon, 0.17 per cent.;

TABLE XVI-D.

Comparison of Eye-Bar Flats with the Preliminary Test.

Heat number.	Preliminary test; ¾-inch rolled round; natural.					Longitudinal strip; cut near edge of eye-bar; natural.				
	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
1	42220	71830	26.25	53.47	58.8	40710	68830	27.00	47.18	59.1
2	41900	66440	28.25	58.96	63.1	41570	71400	26.25	50.08	58.2
3	41880	69760	25.00	52.94	59.8	39780	69460	25.75	44.31	57.2
4	42440	72640	25.00	55.86	57.6	40880	69400	25.00	48.41	58.9
5	41880	74470	26.25	58.37	56.2	41480	72320	24.50	46.78	57.4
6	43670	72720	24.50	54.48	59.9	41310	73640	23.75	35.54	56.1
7	43210	70240	27.50	58.21	61.5	40870	73060	25.60	40.00	56.0
8	41890	68640	25.00	56.09	61.0	41900	76700	25.75	43.76	54.6
9	42020	69890	28.75	57.14	60.6	41070	69080	27.00	44.33	58 9
Av.	42278	70791	26.28	55.61	59.7	41008	71409	25.62	44.60	57.4

phosphorus, 0.014 per cent.; manganese, 0.37 per cent.; sulphur, 0.027 per cent.

SEC. XVId.—*Parallel-sided and grooved tests.*—The United States Treasury Department prescribed the grooved test on marine boiler steels up to the year 1895. The relation existing between the two different systems is shown in Table XVI-F, which gives the results obtained by the Lukens Iron and Steel Company, Coatesville, Pa. from duplicate strips cut side by side from the same plate.

SEC. XVIe.—*Effect of shoulders at the ends of test-pieces.*—The flow of force, by which the tensile tests on the grooved section are rendered almost worthless, occurs also in 2-inch test-pieces when there are shoulders at each end. The difference is

TABLE XVI-E.

Longitudinal and Transverse Strips from Plates.

Composition, per cent.: C, 0.17; P, .014; Mn, 0.37; S, .027.

Average of 100 plates.	Longitudinal.	Transverse.
Ultimate strength; pounds per square inch . .	56060	54540
Elastic limit; pounds per square inch	33350	32260
Elongation in 8 inches; per cent	27.46	27.90
Reduction of area; per cent	51.07	50.57

TABLE XVI-F.

Comparison of Parallel and Grooved (Marine) Sections.

Thickness of plate in inches.	Number of plates tested.	Average ultimate strength; pounds per square inch.			Reduction of area.	
		Grooved.	Parallel.	Difference.	Grooved.	Parallel.
1	4	65600	53100	12500	52.0	58.0
[illegible]	6	62700	52800	9900	51.4	64.5
[illegible]	5	60900	51400	9500	und.	63.2
[illegible]	4	61300	53500	7800	61.7	65.2
[illegible]	8	60600	54100	6500	60.0	66.5

less, but its existence will be shown by the following records. At a certain works it was the custom to cut two tests from one plate of each heat and pull one piece in a section 2 inches long and 1½ inches wide, with shoulders on each end, while the other piece was pulled in a parallel-sided section 8 inches long and 3 inches wide. Table XVI-G gives the results. The records show that in only 71 plates did the 2-inch test show less tensile strength than the 8-inch, and in half of these cases the difference was less than

TABLE XVI-G.

Ultimate Strength of 2-inch Tests with Shoulders, and 8-inch Parallel-Sided Tests.

All plates were rolled direct from the ingot at one heat.

Relation of ultimate strength of 2-inch and 8-inch test-pieces.	Difference in ultimate strength between 2-inch and 8-inch test-pieces; pounds per square inch.	Ultimate strength; 50000 to 58000 pounds per square inch; below .04 per cent. phosphorus.			Ultimate strength; 58000 to 64000 pounds per square inch; below .04 per cent. phosphorus.			Total heats.
		¼ to ⅜ thick.	⅜ to ½ thick.	½ to ¾ thick.	¼ to ⅜ thick.	⅜ to ½ thick.	½ to ¾ thick.	
2 inch gave less strength than the 8 inch.	less than 1000	6	10	3	4	7	4	34
	bet. 1000 and 2000	3	4	2	1	1	. . . .	11
	bet. 2000 and 3000	1	3	. . . .	4	2	. . . .	10
	bet. 3000 and 4000	1	. . . .	1	1	3	1	7
	bet. 4000 and 5000	. . . .	2	. . . .	1	. . . .	. . . .	3
	over 5000	. . . .	. . . .	. . . .	3	3	. . . .	6
	Total	11	19	6	14	16	5	71
2 inch gave more strength than the 8 inch.	less than 1000	28	28	4	2	7	4	68
	bet. 1000 and 2000	28	36	4	8	16	6	98
	bet. 2000 and 3000	15	15	3	8	8	4	53
	bet. 3000 and 4000	4	13	5	3	3	. . . .	28
	bet. 4000 and 5000	5	5	2	. . . .	2	2	16
	over 5000	2	15	2	1	2	1	23
	Total	72	112	20	22	38	17	281

1000 pounds; on the other hand, there were 281 cases where the 2-inch test showed greater strength, and the differences are more marked, the largest group showing an increase of from 1000 to 2000 pounds. It will be shown by Table XVI-L that the width of the piece has little effect upon the strength, so that these records give evidence of the reinforcement of the 2-inch test from the shoulders at the ends.

SEC. XVIf.—*The preliminary test-piece.*—Granting that the test is to be made on a parallel-sided piece, it has been proposed that the steel be tested by making a trial bar, either round or flat, rolled from a small ingot. It is the custom at Steelton to make

TABLE XVI-H.

Comparison of Angles, with the Preliminary Test.

History of test-piece.	No. of heats in average.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 in.; per cent.	Reduction of area; per cent.
Cut from $\frac{5}{16}$-inch and $\frac{3}{8}$-inch angles	39	41300	60190	28.89	58.0
Rolled from 6-inch test ingot	39	42270	60200	26.44	42.4
Cut from $\frac{7}{16}$-inch and $\frac{1}{2}$-inch angles	46	40170	60660	29.05	56.4
Rolled from 6-inch test ingot	46	43070	61360	25.01	40.0
Cut from $\frac{9}{16}$-inch and $\frac{5}{8}$-inch angles	37	39710	61520	28.96	58.6
Rolled from 6-inch test ingot	37	42990	62080	23.10	38.2

such a preliminary test, but this is done merely to classify the metal. If the bar is rolled under proper conditions, its ultimate strength represents the ultimate strength of the finished material, and, without regard to any results on elongation or other qualities, the steel is used or laid aside, but these records have nothing to do with the acceptance or rejection of the material. In other words, this test is our own work, while the inspector is to test the material that he buys, as fully as he may wish, without regard to whether a small test ingot has or has not fulfilled certain requirements.

Table XVI-H compares the data obtained from a large number of charges of acid open-hearth steel having a tensile strength between 56,000 and 64,000 pounds per square inch. They were all

rolled into angles and the charges are grouped according to the thickness of the finished material. The great inferiority of the tests from the 6-inch ingot is easily explained. It is difficult to cast small ingots so that they will not be scrappy, and the bars rolled from them will oftentimes contain flaws; consequently, we break down the ingot to a billet two inches square and chip out the flaws, after which the piece is reheated and gives a perfect bar. It does not receive sufficient work to ensure good elongation, but only the strength of the material is under investigation, and in this respect the results are found to be comparable with the finished material.

SEC. XVIg.—*Comparison of rounds and flats.*—The properties of a flat bar are different from those of a round.

The points involved are three:

(1) The percentage of work on the piece.

(2) The finishing temperature.

(3) The shape of the piece.

(1) The amount of reduction from the bloom or ingot should not play too great a part in the problem, for it is the duty of the manufacturer to so conduct the operation that every piece, no matter how large, shall have sufficient work. But a large section, a 9-inch round, for example, cannot possibly be finished under the same thorough and permeative compression that can be put upon a bar only one inch in diameter or upon a thin flat.

(2) It is for the rolling-mill to arrange that every piece is rolled at a proper temperature, but it is impracticable to finish bars of all thicknesses under identically the same conditions.

(3) The shape of the test-piece has an influence upon the results, but it is difficult to isolate this relation from the effect of work and finishing temperature.

The separation of these three intertwining influences is a complicated problem, the nature of which will be illustrated by Table XVI-I, which gives the results obtained from a large number of heats by cutting two billets from the same ingot and rolling one into a round and the other into a flat. This table discloses the following facts:

(1) Taking both natural and annealed bars, there are 18 comparisons between rounds and flats. The ultimate strength is less in the flat in every case. The elastic limit falls in 17 cases, and

the gain in the exception is slight. The elongation is raised in 16 cases, while in the two exceptions the loss is small. The reduction of area is lowered in 14 cases and raised in four. The elastic ratio is lower in 15 cases, while in the exceptions the increase is small.

(2) Comparing the loss of strength in passing from round to flat, as shown in Table XVI-J, there are nine possible comparisons between the loss in the natural bar and the loss in the an-

TABLE XVI-I.

Comparative Physical Properties of ¾-inch Rounds and 2x⅝-inch Flats.

All bars were rolled from a 4x4-inch billet on the same mill.

	Limits of ultimate strength; pounds per square inch.	Kind of steel.	No. of heats in average.	Ult. strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.		Elastic ratio; per cent	
				Round	Flat	Round	Flat	Round	Flat	Round	Flat	Round	Flat
Natural bars.	56000 to 60000	Bess.	11	58690	56456	42818	41006	27.75	31.45	58 88	56.18	71.38	71.38
		O. H.	4	59568	58180	40600	40400	29.00	30.18	60.78	61.75	68.81	69.51
	60000 to 64000	Bess.	6	62067	60695	45828	43185	27.04	30.42	55.81	56.20	73.00	70.92
		O. H.	7	63187	62089	42905	42441	28.04	30.14	62.16	60.36	68.51	68.36
	64000 to 68000	Bess.	9	66941	64621	47568	45194	26.08	28.42	50.07	47.80	71.31	69.94
		O. H.	....	....	....	....	....	....	....	....	....	....	....
	68000 to 72000	Bess.	8	70457	69773	50268	49000	24.75	26.67	43.30	43.40	71.34	70.31
		O. H.	9	70580	69420	49000	45000	26.88	25.68	61.10	59.30	69.47	64.96
	72000 to 80000	Bess.	4	77440	76000	58760	52240	24.06	23.44	42.26	40.15	69.43	67.98
		O. H.	12	76616	75866	51108	49691	24.52	24.69	58.78	54.40	66.71	65.50
Same bars annealed.	56000 to 60000	Bess.	11	55708	54194	37828	35608	29.14	30.05	66.55	66.18	67.91	65.70
		O. H.	4	54068	51418	31828	30868	28.75	31.06	62.65	60.50	68.82	59.11
	60000 to 64000	Bess.	6	59872	56198	40570	37542	30.18	30.03	65.50	63.83	68.38	66.61
		O. H.	7	58964	55021	35120	31676	29.61	30.36	68.47	60.00	60.17	57.59
	64000 to 68000	Bess.	9	61094	58686	42228	39476	28.25	29.36	62.91	59.01	68.45	65.39
		O. H.	....	....	....	....	....	....	....	....	....	....	....
	68000 to 72000	Bess.	8	65508	64160	44660	42770	26.08	28.69	66.28	59.50	67.76	66.53
		O. H.	2	65500	60950	37665	34000	29.88	26.50	65.90	52.10	67.58	55.67
	72000 to 80000	Bess.	4	71548	68790	47648	43568	25.81	26.86	57.58	51.00	66.59	63.34
		O. H.	12	69408	67618	44005	39408	28.04	25.81	60.54	51.26	63.36	58.27

nealed piece. The ultimate strength falls more in every case in the annealed than it does in the natural bar. The elastic limit falls in six cases and rises to a much less extent in three. The elongation rises in five cases and falls in four. The reduction of area falls in all cases. The elastic ratio falls in five cases and rises in four.

The exceptions and irregularities are not confined to any one kind of steel, so that it is proper to average the losses and gains. The results of such condensation are given in Table XVI-J, which shows the true average of all the heats and not the average of the

TABLE XVI-J.

Round and Flat Bars in the Natural and Annealed States.

Average of all heats given in Table XVI-I	Condition of bar.	Shape of bar.		Gain—+ Loss—— in flat.
		Round	Flat	
Ultimate strength; pounds per square inch,	Natural	66679	65911	—768
	Annealed	62015	59567	—2448
Elastic limit; pounds per square inch,	Natural	46588	45268	—1320
	Annealed	39033	37106	—2527
Elastic ratio; per cent.,	Natural	69.87	68.68	—1.19
	Annealed	63.91	62.29	—1.62
Elongation in 8 inches; per cent.,	Natural	26.48	28.22	+1.74
	Annealed	27.16	28.73	+1.57
Reduction of area; per cent.,	Natural	54.98	54.05	—0.93
	Annealed	61.98	58.12	—3.86

groups. The loss of strength from the round to the flat is much greater in the annealed than in the natural bars, and the elastic limit more than keeps pace with it. The difference can hardly be due to varying work, for the round was reduced to 2.6 per cent. of the area of the billet and the flat to 4.7 per cent., the reduction in both cases being so heavy that the results should be uniform, as far as this factor is concerned. The effect of the finishing temperature may be ignored in the annealed pieces, and yet there is a difference of 2448 pounds per square inch in ultimate strength between the flat and round.

The natural bars show less difference, which would indicate that the finishing temperature has raised the strength of the flat more than the round. This is contrary to the condition just noted that the reduction in rolling was less in the case of the flat, but it is

in accord with the evident fact that a thin bar would cool faster than a round bar of somewhat less sectional area. The effect of the finishing temperature, therefore, was to raise the tensile strength of the flat more than it did the round, but not enough to overcome the difference in physical properties caused by the shape of the bars.

The reduction of area is less in the case of the flat, and the difference is more marked in the annealed than in the natural bars. The elongation is higher in both kinds of flats than in the corresponding rounds, but the difference is greater in the natural bars. This appears, at first sight, to be an exception, but a decrease in gain is equivalent to a loss, and this brings it in accord with the decrease in the ductility, as shown by the lessened reduction of area. The net result is as follows:

(1) Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation, and a slightly lower reduction of area.

(2) This difference is caused not by reason of a different finishing temperature, but in spite of it.

SEC. XVIh.—*Comparative properties of rounds of different diameter.*—The variation in strength of bars is not confined to pieces of different shape, for it will exist in rounds of different diameters. In Table XVI-K are given the results on a number of rivet rods where several tests were made from the same heat. All the charges were of the same quality of steel, ranging from .11 to .15 per cent. in carbon, .02 to .04 per cent. in phosphorus, and .022 to .038 per cent. in sulphur.

The number of heats would not be sufficient to justify a general conclusion if there were only a single bar of each heat, but each figure is the average of from 4 to 16 determinations. In the comparison of the three-quarter and seven-eighth inch rounds there were 112 tests of the smaller size and 94 of the larger, while in the comparison of the five-eighth and three-quarter inch there were 32 tests of the former and 34 of the latter. No average is given where less than four tests were taken of the same size from the same heat. Comparing the seven-eighth inch with the three-quarter inch bars, it will be found that in the larger size the following changes occurred:

(1) The ultimate strength was lowered in ten heats and raised

TABLE XVI-K.

Comparative Properties of Rounds of Different Diameters.

Each figure is an average of from 4 to 16 determinations.

Heat No.	Ult. strength; pounds per square inch.		Elastic limit; pounds per square inch.		Elongation in 8 inches; per cent.		Reduction of area; per cent.	
	¾ in.	⅞ in.	¾ in.	⅞ in.	¾ in.	⅞ in.	¾ in.	⅞ in.
11478	60028	58215	40023	39433	29.53	30.63	60.56	60.80
11489	59179	57671	37836	37079	29.81	31.96	63.45	62.51
11550	58228	57707	39219	37482	29.78	30.40	62.70	64.10
11604	57833	56078	39673	38210	32.45	30.75	66.50	62.60
12796	57960	57517	38630	38288	30.14	31.04	60.45	63.50
11945	57456	56758	38498	37208	29.81	30.59	61.60	59.60
12006	57550	55678	38305	36485	29.58	30.58	60.81	65.05
12007	57943	57408	38752	37498	30.26	31.44	64.18	61.10
12519	56774	56106	39015	37495	29.80	31.84	62.40	59.45
2082	59670	56963	39050	36810	29.67	30.50	64.50	57.90
2073	59772	56425	39041	37007	30.25	32.79	64.90	63.70
Av.	58582	57156	38931	37550	30.10	31.09	62.91	61.88
	⅝ in.	¾ in.	⅝ in.	¾ in.	⅝ in.	¾ in.	⅝ in.	¾ in.
11478	60423	60028	41378	40023	29.44	29.52	65.40	60.56
12007	58120	57943	38900	38752	30.16	30.38	64.55	64.18
1523	59683	59785	42300	38756	30.06	31.66	64.22	65.40
2300	59421	59425	41276	39860	30.00	30.81	64.86	64.65
Av.	59809	59295	40902	39843	29.92	30.47	64.76	63.69
	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.
12334	57820	59813	37770	37298	30.85	32.25	63.15	61.55
	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.	⅞ in.	1⅛ in.
12368	62688	60480	39985	36573	30.60	31.97	62.28	58.80
	. . . . .	1¼ in.	. . . . .	1¼ in.	. . . . .	1¼ in.	. . . . .	1¼ in.
11517	. . . . .	60688	. . . . .	36770	. . . . .	32.02	. . . . .	54.3

in one, the average showing a decrease of 1426 pounds per square inch.

(2) The elastic limit was lowered in all cases, the average showing a decrease of 1381 pounds per square inch; the elastic ratio was reduced from 66.5 per cent. to 65.7 per cent.

(3) The elongation was raised in ten cases and lowered in one, the average showing an increase of 0.99 per cent.

(4) The reduction of area was lowered in seven heats and raised in four, the average showing a decrease of 1.08 per cent.

Comparing the five-eighth and three-quarter inch, it will be found that in the larger size the following alterations have taken place:

(1) The ultimate strength was lowered in three heats and raised

a trifling amount in one, the average showing a decrease of 1114 pounds per square inch.

(2) The elastic limit was lowered in three cases and raised in one, the average showing a decrease of 1454 pounds per square inch; the elastic ratio was reduced from 68.7 per cent. to 67.5 per cent.

(3) The elongation was raised in every case, the average showing an increase of 0.55 per cent.

(4) The reduction of area was lowered in three heats and raised in one, the average showing a decrease of 1.07 per cent.

The testimony of these records is corroborated by the data on the larger diameters. Only one heat is given on each of these sizes, but there were from twelve to sixteen bars in each case, and as the steel was of the same manufacture in all particulars the results may be accepted as comparable. It seems certain that larger bars will give a lower ultimate strength, a lower elastic limit, a

TABLE XVI-L.

Effect of Changes in the Width of the Test-Piece.

	Thickness in inches.	No. of heats in av.	Width of test-piece in inches.					
			3	2	1½	1	¾	½
Ultimate strength; pounds per square in.		2	72510	73480	73840	78250	74420	75440
		8	72020	72220	72420	72643	71563	73581
		8	67945	68500	68710	68220	68050	68940
		2	73840	73550	74580	73870	73520	76130
		10	68111	68224	67950	67890	68388	67442
	True av.	30	69784	70030	70176	69968	69872	70578
Elastic limit; pounds per square in.		2	. . . . .	41685	42185	41965	42975	40655
		8	. . . . .	42485	42958	42711	42798	40958
		8	. . . . .	41600	42190	41630	41680	45830
		2	. . . . .	45840	46740	46085	46285	51830
		10	. . . . .	45939	45846	45664	46676	45659
	True av.	30	. . . . .	43571	43588	43579	44023	46235
Elongation in 8 inches; per cent.		2	29.37	28.87	28.37	25.00	23.75	24.25
		8	29.78	27.88	27.66	26.06	24.78	24.88
		8	30.75	28.60	27.72	27.34	26.31	24.06
		2	28.37	27.50	25.62	25.87	25.12	23.50
		10	28.50	27.28	26.65	25.85	24.98	23.98
	True av.	30	29.52	27.92	27.25	26.25	25.21	23.87
Reduction of area; per cent.		2	52.7	56.1	56.3	53.6	52.3	56.0
		8	53.7	54.2	57.3	57.2	57.6	58.9
		8	56.8	58.9	59.9	59.6	59.7	61.0
		2	52.1	53.9	56.8	60.0	58.2	56.1
		10	55.0	56.2	57.9	58.8	59.5	60.0
	True av.	30	54.79	56.23	58.09	58.32	58.48	59.45

lower elastic ratio, a better elongation, and a lower reduction of area. Some of these characteristics may be due to differences in finishing temperature, but the data on elastic limits show that the pieces were all rolled at nearly the same degree of heat, and such small variations are not sufficient to account for the increase in the elongation.

This variation in physical qualities, as produced by differences in diameter, has been discussed by Appleby.* In common with others, he makes the fundamental mistake of rolling all the bars to one size, viz., 1½ inches in diameter, and turning the test specimens from these bars. A test-piece of one-half inch in diameter thus obtained will be merely the core or center of the original bar, and will be inferior both chemically and physically. On the one hand it embraces the area of maximum segregation, while on the other it has not undergone the compression that the exterior of the bar has received in the rolls, and a comparison of the bars is invalid. The method, which I have employed, of comparing rolled bars of different sizes in the form in which they left the rolls, also presents complicating conditions, inasmuch as the effect of work is not the same on large and on small sections, but it has the advantage that it represents actual conditions.

SEC. XVII.—*Influence of the width of the test-piece.*—Conclusive testimony that variations in the elongation may be due solely to the cross-section of the test-piece is furnished by Table XVI-L, which gives the results obtained in breaking strips of different width when the pieces were cut side by side from the same plate.

No comparison can be made between the different thicknesses, since the individual heats were not the same, but in the matter of widths the case is otherwise, for every heat in the group was tested in all the widths, the bars from each heat being cut from the same small strip of plate, and this should give a valid basis of comparison.

The conclusions are as follows:

(1) Variations in the width of the test-piece have little effect upon the ultimate strength per square inch.

(2) They probably have little influence upon the elastic limit. The narrowest pieces show a decided increase, but this needs corroboration. The three-inch pieces were pulled at the works of the

* *Proc. Inst. Civil Eng.* (England), Vol. CXVIII, pp. 395–417.

Pottstown Iron Company, being beyond the capacity of the machine at Steelton, and the determinations of elastic limit are, therefore, not comparable.

TABLE XVI-M.

Influence upon the Elongation of Changes in Width (Barba).

Number of sample.	Dimensions in inches.			Ratio of width to thickness.	Elongation; per cent.
	Length.	Width.	Thickness.		
1	8.94	0.394	0.394	1	31.0
2	8.94	0.787	0.394	2	34.0
3	8.94	1.181	0.394	3	35.0
4	8.94	1.575	0.394	4	37.2
5	8.94	1.964	0.394	5	39.0
6	8.94	2.362	0.394	6	40.8
7	8.94	2.756	0.394	7	38.5
8	8.94	3.150	0.394	8	34.5

(3) The elongation increases regularly as the width increases.

(4) The reduction of area decreases as the width increases.

The same subject was investigated by Barba,* his results being given in Table XVI-M. The figures show a continual increase in elongation until the width is six times the thickness, after which the stretch grows less. The latter point is not important in practice, since there is no occasion to use such a wide section, and in plates of ordinary thickness the strength of such pieces is beyond the capacity of most machines.

TABLE XVI-N.

Effect of an Increase of Width upon the Elongation.†

Thickness in in.		Width of piece in inches.				
		1	1¼	1¾	2¼	8
½	Number of pieces	180	120	80	80	18
	Average ultimate strength; lbs. per sq. inch	57960	57878	58102	57800	57670
	Elongation in 8 inches; per cent.	26.27	26.98	28.01	29.49	30.83
⅝	Number of pieces	20	25	20	20	20
	Average ultimate strength; lbs. per sq. inch	56690	57001	56720	56980	55970
	Elongation in 8 inches; per cent.	26.92	26.96	27.91	30.17	31.02

The increase in elongation in greater widths has been shown by E. A. Custer, of the Baldwin Locomotive Works, Philadelphia, Pa.,

* *Resistance des Materiaux; Memoires de la Societe des Ingenieurs Civils.* Vol. I, 1880, p. 682.

† E. A. Custer, private communication.

who has given me the results obtained by him in testing boiler plate. The steel ranged in strength from 55,400 to 61,300 pounds per square inch, and was of nearly uniform chemical composition. The records are given in Table XVI-N.

SEC. XVIj.—*Influence of a change in length.*—To determine the relative elongation with varying length, I carried out the following investigation: Twenty rods, three-quarter inch in diameter, were selected from one heat of acid open-hearth steel. From each rod seven bars were cut, one of which was tested in a length of 2 inches, and one each in 4, 6, 8, 10, 12 and 14 inches. The results are given in Table XVI-O. The individual records of elongation are shown to prove that the averages are not formed by the combination of unlike members. These data are plotted in Curve *AA*, Fig. XVI-A. A similar series of tests was made by Barba,* the results

TABLE XVI-O.

Influence of Changes in the Length.

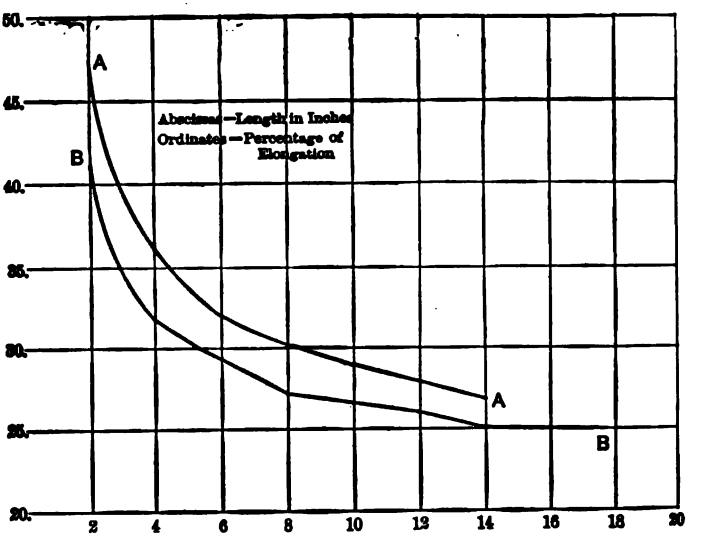
¾-inch rounds; Pennsylvania Steel Company acid open-hearth rivet steel.

	No. of bar.	Length of test-piece in inches.						
		2	4	6	8	10	12	14
Ult. strength; lbs. per square inch.	Av.	60085	60848	60099	60123	60068	60059	60066
Elastic limit; lbs. per square inch.	Av.	42548	43134	42951	43159	43161	43024	43284
Elastic ratio; per cent.	Av.	70.11	71.48	71.47	71.78	71.85	71.64	71.96
Reduction of area; per cent.	Av.	66.7	66.9	67.1	66.8	67.3	67.2	67.1
Elongation; per cent.	1	47.50	35.00	30.67	30.50	28.20	27.17	26.43
	2	46.00	35.50	30.67	30.50	29.80	27.67	26.43
	3	47.00	34.50	32.33	28.25	27.80	27.50	26.43
	4	48.50	35.50	32.00	30.25	28.30	25.00	27.00
	5	47.00	35.50	33.00	28.75	29.00	27.17	28.14
	6	46.50	39.00	32.67	28.75	31.60	29.33	28.21
	7	47.50	37.50	31.33	30.50	29.40	27.33	25.71
	8	46.00	33.00	30.00	30.00	26.60	28.00	24.43
	9	47.50	35.50	34.33	31.75	30.40	29.33	28.21
	10	47.50	36.00	30.33	29.50	28.80	28.50	25.29
	11	49.60	34.75	30.00	31.00	30.30	27.75	27.57
	12	49.00	36.50	31.33	29.50	27.80	29.33	28.71
	13	47.00	35.50	32.33	29.00	26.60	27.00	26.43
	14	47.50	38.00	31.67	32.75	31.00	30.50	26.79
	15	48.50	37.00	33.33	30.75	29.00	28.33	27.64
	16	47.50	37.00	33.00	31.25	31.00	27.75	29.29
	17	48.50	37.00	32.50	29.00	28.20	27.33	27.21
	18	46.00	35.00	34.67	28.75	28.00	28.75	25.86
	19	47.00	37.00	33.00	30.00	27.50	27.00	26.29
	20	47.50	37.50	34.33	32.50	30.00	26.25	28.14
	Av.	47.43	36.11	32.17	30.16	28.96	27.87	26.76

* *Resistance des Materiaux; Memoires de la Societe des Ingenieurs Civils.* Vol. I, 1880 p. 682.

being given in Table XVI-P, and plotted in Curve *BB*, Fig. XVI-A.

The linear elongation of a fractured bar is made up of two factors. First, the excessive stretch in the immediate neighborhood of the break, due to the deformation known as "necking." Second, the "permanent set" throughout the rest of the bar. The first factor will bear a greater ratio to the sum total as the length grows less, and a less ratio as the length increases. Therefore, if the length of the piece is reduced so that it is all included in the region



Construction points.				
No.	Curve AA.		Curve BB.	
1	x = 2	y = 47.43	x = 1.97	y = 42.0
2	x = 4	y = 36.11	x = 3.94	y = 32.0
3	x = 6	y = 32.17	x = 5.91	y = 29.2
4	x = 8	y = 30.16	x = 7.87	y = 27.2
5	x = 10	y = 28.96	x = 9.84	y = 26.6
6	x = 12	y = 27.87	x = 11.81	y = 26.0
7	x = 14	y = 26.76	x = 13.78	y = 25.1
8	. . . . .		x = 15.75	y = 25.0
9	. . . . .		x = 17.72	y = 24.9

FIG. XVI-A.—ELONGATION WITH VARYING LENGTH.

of necking, as, for instance, when the piece is only 2 inches long, the percentage of elongation will increase rapidly. On the other hand, when the length is increased beyond 14 inches, the ratio of

the first factor to the second is not great, and the change in total percentage with each linear increment is not marked.

If the length were zero, the percentage of elongation would be infinite, while, if the length were infinite, the percentage of extension would be represented by the permanent set of those portions of the bar where no necking occurs. The true curve expressing the law of relative elongation is undoubtedly an hyperbola, one asymptote of which will correspond to a length of zero, while the other will be the percentage due to the permanent set, which will vary with every kind of steel.

TABLE XVI-P.

Influence upon the Elongation of Changes in the Length.*

No. of bar.	Dimensions; inches.		Ratio of length to diameter.	Elongation; per cent.
	Length.	Diameter.		
1	1.97	0.677	2.91	42.0
2	3.94	0.677	5.81	32.0
3	5.91	0.677	8.72	29.3
4	7.87	0.677	11.60	27.2
5	9.84	0.677	14.50	26.6
6	11.81	0.677	17.40	26.0
7	13.78	0.677	20.30	25.1
8	15.75	0.677	23.30	25.0
9	17.72	0.677	26.20	24.9

The elongation in the portion of the piece which does not undergo "necking" may be calculated from Table XVI-O. As a matter of experience, a length of about two inches includes the region wherein necking occurs, and this length is a constant, no matter what the total length of the test-piece may be. A test-piece two inches long is practically all "neck," while in one four inches long there will be one length of two inches which is all neck, and two inches which will remain nearly a true cylinder after fracture. In the case of the 2-inch test-pieces, given in Table XVI-O, the average elongation was 47.43 per cent., representing a linear elongation of 0.9486 inches. In the case of the 4-inch test-pieces the stretch, by the above assumption, was the same in the necked region, while the total elongation was 36.11 per cent., representing a linear elongation of 1.4444 inches. Hence, the elongation in the two inches of the cylindrical portion was 1.4444—0.9486=0.4958 inches, or 24.79 per cent.

* Barba, *Proc. French Soc. Civil Eng.*, Vol. I, 1880, p. 682.

In the same manner the elongation in the cylindrical portion may be calculated for all the different lengths given in Table XVI-O. The results are as follows, in per cent.:

$4''=24.79$; $6''=24.54$; $8''=24.40$; $10''=24.34$; $12''=23.96$; $14''=23.82$.

There is a decrease in elongation with an increase in length, and the relation is so regular that it is probably due to something besides experimental error. If the necking be assumed to take place within a length of only one inch, instead of two inches, the calculated percentage of elongation will be a little more uniform, but the improvement is so slight, even with this extreme hypothesis, that some other cause is shown to be at work.

I believe that the true explanation is in the fact, which was called to my attention by Mr. W. R. Webster, that the breaking speed varies with each length. The speed of the machine was the same in every case, but a constant speed of the grips does not mean a constant rate of distortion in the bar. In the case of the 2-inch piece, the stretch was 47.43 per cent., indicating a linear extension of 0.95 inches; in the case of the 14-inch piece the stretch was 26.76 per cent., indicating an extension of 3.75 inches. The rate of distortion, therefore, was four times as great in the 2-inch test as in the 14-inch bar, and this condition would give a higher elongation with each decrease in length, as shown in Section XVIm. Owing to this complication it is impossible to deduce a theoretically accurate answer from the foregoing data, but in a three-quarter inch round bar of infinite length, of the steel shown in Table XVI-O, the elongation would be about 24 per cent.

SEC. XVIk.—*Tests on eye-bars.*—Through the courtesy of The Union Bridge Company, of Athens, Pa., I have had access to its records of eye-bar tests, and have classified them to determine the influence of width, thickness and length upon the physical properties. All bars which showed 100 per cent. crystalline fracture, and pieces of miscellaneous lengths when there were less than three bars of the same steel in the group, were omitted. A few pieces were discarded when the elongation in 12 inches was the same as in the full length, for this indicates either a clerical error or that fracture took place in the eye. After these eliminations only three works were represented, two of them by both open-hearth and Bessemer steel. The records are given in Table XVI-Q, and show

TABLE XVI-Q.

Physical Properties of Eye-Bars.

NOTES.—The bar was broken in full-sized section, but the elongation here given is the percentage in the 12 inches which included the fracture. "Narrow" signifies not over 6 inches wide, the average being about 5 inches; "Wide" signifies over 6 inches wide, the average being about 7 inches. "Thin" signifies under 1¼ inches thick, the average being about 1 inch. "Thick" signifies not less than 1¼ inches thick, the average being about 1⅞ inches.

Name of maker.	Method of manufacture.	Limits of ultimate strength in group; pounds per square inch.	Relative thickness of piece.	Relative width of piece.	Number of heats in average.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	Elongation in 12 inches; per cent.	Reduction of area; per cent.
A	Open-hearth.	54000 to 64000	Thin	Narrow	109	61528	39017	63.4	24.72	49.6
				Wide	18	59950	37937	63.3	28.72	48.6
			Thick	Narrow	33	60888	37470	61.9	27.43	50.0
				Wide	11	60907	36698	60.8	30.61	46.8
		64000 to 74000	Thin	Narrow	72	66702	41967	62.9	22.58	47.5
			Thick	Narrow	19	66570	41858	62.9	24.22	47.5
	Bessemer.	54000 to 64000	Thin	Narrow	102	59557	36086	60.6	24.43	50.3
				Wide	5	61988	38706	62.4	26.20	44.2
			Thick	Narrow	19	60855	36166	59.4	24.16	47.8
				Wide	26	60982	37019	60.8	27.96	48.1
		64000 to 74000	Thin	Narrow	22	66441	41665	62.7	21.93	47.3
				Wide	6	66947	36980	58.7	22.43	45.0
			Thick	Narrow	3	67870	37103	55.1	20.00	42.6
				Wide	3	67263	37290	55.4	23.00	41.8
B	Bessemer.	54000 to 64000	Thin	Narrow	47	59379	35395	59.6	24.08	49.2
				Wide	19	58582	35141	60.0	27.47	47.8
			Thick	Narrow	18	59355	34162	57.6	24.83	46.4
				Wide	61	59536	34408	57.8	25.63	46.4
		64000 to 74000	Thin	Narrow	21	66231	40756	61.5	20.19	47.7
				Wide	5	67184	40766	60.7	25.76	49.3
			Thick	Wide	22	66874	37880	56.6	23.02	45.0
	Open-hearth.	54000 to 64000	Thin	Narrow	103	59018	33901	57.4	23.79	48.8
				Wide	23	59950	32650	54.5	26.65	44.8
			Thick	Narrow	24	58985	33460	56.7	24.80	46.6
				Wide	55	58454	31971	54.7	29.22	48.0
		64000 to 74000	Thin	Narrow	23	66280	40833	60.9	20.18	44.7
				Wide	3	69850	39506	57.0	20.80	36.3
			Thick	Narrow	3	65690	38427	58.5	23.50	44.7
C	Open-hearth.	54000 to 64000	Thin	Narrow	121	60558	35592	58.8	23.57	48.7
				Wide	18	59866	34053	57.4	26.58	46.1
			Thick	Narrow	20	60870	34440	56.6	25.20	48.2
				Wide	21	60240	33245	55.2	29.07	46.2
		64000 to 74000	Thin	Narrow	81	66515	39206	58.9	22.06	46.2

that there is no radical difference in the character of the metal furnished by the three makers, or between the two methods of manufacture. This does not disprove the statement that Bessemer metal is less reliable under continued shock, but it does allow the averaging of all the records, in order to increase the number of members in each group.

The result of such combination will be found in Table XVI-R, wherein all pieces of the same length and section are added together. The number of bars does not agree in each case with the number in the previous list. Thus Table XVI-Q shows 83 bars that

TABLE XVI-R.

Properties of Eye-Bars, According to Length, Width and Thickness.

Kind of bar.	Number of group.	Number of heats in group.	Limits of length of pieces in group; feet.	Average length of group; feet.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Elongation in full length; per cent	Elongation in the 12 in. including the fracture; per cent.	Reduction of area; per cent.
Narrow and thin; 54000 to 64000 pounds per square inch.	1	65	13 to 16	14.8	60070	35890	18.56	24.55	48 97
	2	132	17 to 20	18.6	59950	36160	16.17	23.98	49.40
	3	118	21 to 25	22.7	60280	35940	15.56	24.26	48.81
	4	82	26 to 30	28.1	60140	36580	15.26	24.35	49.95
	5	71	31 to 35	33.2	60120	35990	13.81	23.81	50.11
	True av. A	468	all lengths	. . .	60110	36100	. . .	24.17	49.40
Wide and thin; 54000 to 64000 pounds per square inch.	6	15	13 to 16	14.8	59890	35730	17.53	27.53	46.75
	7	21	17 to 20	19.0	59050	34070	17.18	26.79	45.13
	8	22	21 to 25	22.8	60860	35540	15.92	26.00	45.51
	9	14	26 to 30	28.1	58890	33960	14.94	29.61	47.89
	True av. B	72	all lengths	. . .	59540	34840	. . .	27.36	46.21
Narrow and thick; 54000 to 64000 pounds per square inch.	10	38	17 to 20	17.9	60050	35770	17.36	25.94	48.17
	11	38	21 to 25	22.8	61060	36040	15.57	24.46	46.79
	12	17	26 to 30	28.0	57730	32380	15.38	26.88	49.28
	True av. C	98	all lengths	. . .	60050	35260	. . .	25.50	47 80
Wide and thick; 54000 to 64000 pounds per square inch.	13	18	10 to 13	12.0	59708	35130	19.20	25.90	46.10
	14	22	13 to 16	14.8	59460	33990	16.90	23.02	47.97
	15	24	17 to 20	18.9	59080	33080	17.09	23.36	45.92
	16	67	21 to 25	23.2	59090	34270	15.98	27.42	46.94
	17	32	26 to 30	27.8	59360	34380	15.84	29.98	48.05
	18	11	31 to 35	33.1	58480	33090	16.50	40.51	46.15
	True av. D	174	all lengths	. . .	59540	34080	. . .	28.13	47.13
Narrow and thin; 64000 to 74000 pounds per square inch.	19	25	13 to 16	14.7	66590	40830	16.06	21.68	47.13
	20	58	17 to 20	18.5	66620	40420	15.32	21.27	46.19
	21	64	21 to 25	22.9	66230	40730	14.91	22.28	46.84
	22	33	26 to 30	28.7	66150	40590	14.09	22.27	46.36
	23	34	31 to 35	33.1	66560	40620	14.50	20.78	47.55
	True av. E	214	all lengths	. . .	66420	40620	. . .	21.82	46.74

are classed as "wide and thin" and as having a tensile strength between 54,000 and 64,000 pounds, while Table XVI-R gives only 72 bars. This arises from the fact that some of the 83 bars were shorter than 13 feet or longer than 30 feet, and that there was not a sufficient number of any one size to warrant combining them. The elongation in 12 inches and the reduction of area will be independent of the length of the bar, so that each of the divisions is again summarized in the true averages, *A*, *B*, *C* and *D*. The influence of width will be found by comparing *A* with *B*, and *C* with *D*, and the influence of thickness by comparing *A* with *C*, and *B* with *D*.

The average elongation in 12 inches of the wider bars is about 3 per cent. better than the narrow pieces, while the narrow bars are superior in reduction of area. The thick bars give one per cent. more elongation, but the difference in thickness does not have a marked effect upon the reduction of area. By analyzing the individual records of the table, it will be seen that corroborative evidence is at hand of the correctness of the averages. There are seven comparisons for width, viz., 1 to 6, 2 to 7, 3 to 8, 4 to 9, 10 to 15, 11 to 16, 12 to 17; there are seven comparisons for thickness, viz., 2 to 10, 3 to 11, 4 to 12, 6 to 14, 7 to 15, 8 to 16, 9 to 17.

TABLE XVI-S.

Properties of Eye-Bars, Classified According to Length.

Number of heats in group.	Limits of length in group; feet.	Average length of group; feet.	Average ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Elongation in full length; per cent.	Elongation in the 12 inches including the fracture; per cent.	Reduction of area; per cent.
41	10 to 12	11.8	59880	35240	18.07	34.68	46.95
102	13 to 16	14.8	59880	35460	18.05	35.75	48.42
215	17 to 20	18.6	59770	35540	16.58	35.04	48.37
245	21 to 25	22.9	60880	35460	15.75	35.37	47.72
145	26 to 30	28 0	59620	35810	15.37	36.36	49.25
82	31 to 35	33.1	59000	35470	14.17	34.78	49.85
830	all lengths	. . . . .	59980	35440	. . . . .	35.41	48.42

In every case the wider and the thicker pieces gave the greater elongation in 12 inches. The narrow pieces gave the better reduction of area in every case except one, and in this instance the dif-

ference was trifling. In thickness the results on reduction of area are contradictory, there being three cases where the thin bars were superior and four cases where the thick were better. An increase in width or an increase in thickness improves the elongation in the 12 inches that includes the fracture, but the reduction of area is improved in less measure or not at all.

Applying the same method of inspection to the records of elongation in full length, the wide bars were superior in four cases and inferior in three cases, while the thick bars were superior in five cases and inferior in two cases. Thus there seems to be quite a difference between the records of full-length tests and those from 12-inch lengths, so that it is justifiable to conclude that while wider and thicker bars do give greater elongation after fracture, the advantage is confined to the region of the "necking," and the per-

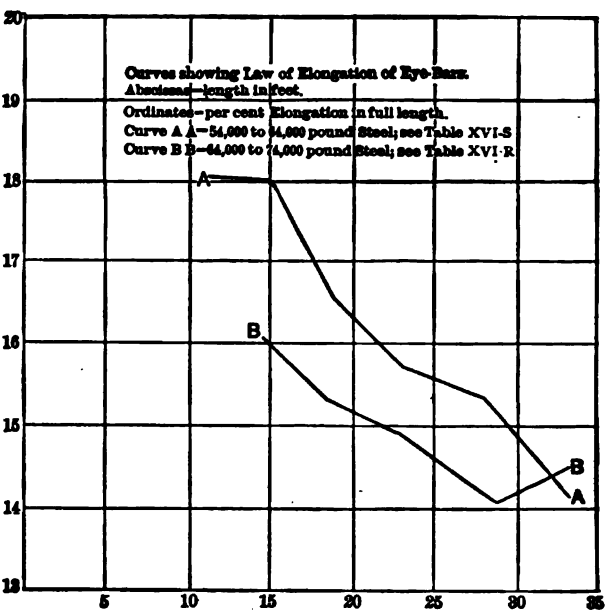


FIG. XVI-B.—LAW OF ELONGATION OF EYE-BARS.

centage of stretch throughout the body of the bar is independent of the section. If this is true, it is a most important fact and has a wide application in structural engineering.

Since there is little, if any, difference in the percentage of elon-

gation in pieces of the same length, although they be of different section, it becomes possible to further combine the records by putting together all widths and thicknesses and classifying by length

TABLE XVI-T.

Proportion of Rejections Caused by Applying a Standard Sliding Scale of Elongation to the Eye-Bar Records in Table XVI-Q.

NOTE.—The standards assumed are the same as specified for different classes of metal in Section XVIII g

	Name of maker.	"A."				"B."				"C."		Total for all kinds.		
	Kind of steel.	Bessemer.		Open-hearth.		Bessemer.		Open-hearth.		Open-hearth.				
Length of bars; in feet.	Standard of elongation; per cent.	No. of bars.	No. below standard.	No. of bars.	No. below standard.	No. of bars.	No. below standard.	No. of bars.	No. below standard.	No. of bars.	No. below standard.	No. of bars.	No. below standard.	Per ct. below standard.
Specification I. Ultimate strength, 54000 to 64000 pounds per square inch. (See Class VI, Section XVIIIg.)														
10 to 20	14.0	64	4	82	10	58	1	60	10	105	24	369	49	13
21 to 25	13.0	47	0	57	8	43	6	85	16	83	7	245	36	11
26 to 30	12.5	34	1	23	0	28	8	30	8	17	9	145	19	13
31 to 35	12.0	26	2	11	2	11	5	21	7	25	5	94	25	27
Total, all lengths,		171	7	153	15	145	15	206	41	180	41	853	119	14
Specification II. Ultimate strength, 64000 to 74000 pounds per square inch. (See Class VIII, Section XVIIIg.)														
10 to 20	12.5	30	0	14	2	10	0	10	5	38	10	102	17	17
21 to 25	12.0	36	1	10	2	23	8	7	4	17	6	93	16	17
26 to 30	11.5	11	0	4	0	11	4	6	3	10	1	43	6	14
31 to 35	11.0	14	0	. .	. .	4	0	6	0	16	1	40	1	3
Total, all lengths,		91	1	34	4	48	5	29	12	81	18	286	40	14

alone. This is done in Table XVI-S. It may be noticed that there are 41 bars running between 10 and 12 feet in length, while in Table XVI-R there are only 18 of this size. This arises from the fact that there were a few of this length in each of the groups as classified by section, but they were not in sufficient number to be of value for comparison, except in Group 13 (see Table XVI-R). In Table XVI-S these scattering bars are combined with Group 13 to have a larger number in the average. The results are plotted in Fig. XVI-B, which shows the law of elongation in long bars. A further point is the proportion of bars that fall below a given standard, since an average may be made up of widely different kinds of metal, or it may be made from a uniform product.

Table XVI-T gives an analysis of the records showing the number and percentage of bars in each division which give less than the standard percentage of elongation.

The number of rejections on longer lengths is fully as great as

TABLE XVI-U.

Alteration in Physical Properties by Rest after Rolling.*

Number of group.	Limits of ultimate strength; pounds per square inch.	Hand rounds.						Guide Rounds.					
		No. of bars tested.		Alteration. Gain = + Loss = —				No. of bars tested.		Alteration. Gain = + Loss = —			
		Less than 24 hrs. rest.	More than 24 hrs. rest.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Less than 24 hrs. rest.	More than 24 hrs. rest.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
I	55000 to 60000	.	.	. . .	. . .	. . .	. . .	6	10	+719	+437	+.65	+ .26
II	60000 to 65000	10	6	—1207	+885	+1.11	+2.14	10	22	—453	+506	+.73	+1.13
III	65000 to 70000	32	12	— 471	—180	— .25	+2.07	22	36	—170	+382	+.38	+1.45
IV	70000 to 75000	21	20	+ 302	+197	+ .66	+2.95	24	36	—166	+688	+.44	+1.14
V	75000 to 80000	10	8	— 809	+107	+1.06	+6.76	35	47	—314	+201	—.51	+2.23
VI	80000 to 85000	7	8	+ 213	+ 86	+ .29	+ .44	16	20	—165	+767	+.42	+1.24
VII	85000 to 90000	.	.	. . .	. . .	. . .	. . .	8	16	+ 92	+525	+.46	+ .62
Av. of all tests.		80	48	— 394	+109	+ .56	+2.87	121	197	—270	+507	+.32	+ .99

* *Notes on Results Obtained from Steel Tested Shortly after Rolling. Amer. Soc. Mech. Eng.*, Vol. IX, p. 38.

with shorter bars, and this proves that the specified decrease in elongation for an increase in length is not greater than should justly be allowed. In the bars made by *"A"* the rejections amount to 4 per cent. in Bessemer metal, and 10 per cent. in open-hearth; in those made by *"B"* they are 10 per cent. in the Bessemer and 20 per cent. in the open-hearth, while with *"C"* they are 23 per cent. Taking into consideration that the records cover only the products of large and well-known works, and that all bars having a crystalline fracture and those breaking in the eye were discarded, it must be acknowledged that the standard specifications call for good material.

SEC. XVII.—*Alterations in steel by rest after rolling.*—In addition to the variations caused by differences in the working of the test-piece and in its shape, there is another factor in the length of time which elapses between rolling and testing. This subject was investigated at The Pennsylvania Steel Works by E. C. Felton, now president of the company, a condensation of whose work is given in Table XVI-U. The changes are not strongly marked, but there seems to be a molecular rearrangement, for several hours after the bar is cold, whereby there is a lowering of the elastic limit, and an increase in the ultimate strength, the elongation, and the reduction of area.

SEC. XVIm.—*Errors in determining the physical properties.*—It is the rule in practical work that two sides of the test-piece are not machined, and hence it is impossible to make a perfectly accurate measurement. In order to find how great an effect may be caused by such errors and by differences in machines and the method of operating them, the experiment was tried of sending a bar from six different acid open-hearth heats to six different testing laboratories. The pieces were rolled flats, 2"x $\frac{5}{8}$", and each series was made up of one piece from each of the six bars.

All pieces were tested in the shape in which they left the rolls without machining, and although the edges were not perfectly smooth, they were so nearly true that only one operator referred to any difficulty in making a true measurement. Table XVI-V exhibits the results reported. The bars were tested by The Central Iron and Steel Works, Harrisburg, Pa.; The Baldwin Locomotive Works, Philadelphia, Pa.; The Pottstown Iron Company, Pottstown, Pa.; The Carnegie Steel Company, Pittsburg, Pa.; The Car-

bon Steel Company, Pittsburg, Pa., and The Pennsylvania Steel Company, Steelton, Pa., but the identity of the different works is concealed in the table under the letters *A, B, C,* etc.

There are quite important variations in every one of the factors. Moreover, the divergence is not the result of averaging erratic individuals, for whenever one average is higher than another the majority of the bars are higher when taken separately. The variations

TABLE XVI-V.

Physical Properties, as Determined by Different Laboratories.

NOTE.—All bars were rolled flats, 2"x⅝", and were not machined.

	Number of heat.	Tested by					
		A.	B.	C.	D.	E.	F.
Ultimate strength; pounds per square inch.	10027	58180	57880	58560	57710	57980	59230
	10028	60790	60140	61740	60060	60060	61880
	10060	63560	63830	64580	63180	63450	64260
	10065	60840	61170	62180	60440	61290	62200
	10066	62340	62700	63480	61970	62680	64170
	10072	61160	62190	61780	61390	61640	62110
	Average,	61220	61288	62087	60795	61275	62308
Elastic limit; pounds per square inch.	10027	42400	37850	38900	37490	39020	39730
	10028	42200	37940	41400	38720	39780	41230
	10060	43620	40780	42540	38940	40740	42770
	10065	41540	38150	42350	38710	40210	41250
	10066	42610	40850	42110	38905	40180	42140
	10072	41400	37650	41770	38710	40950	39880
	Average,	42295	38708	41495	38579	40138	41345
	Elastic ratio,	69.1	63.2	66.9	63.5	65.5	66.4
Elongation in 8 inches; per cent.	10027	29.25	29.00	30.50	30.37	30.75	29.75
	10028	30.75	30.00	32.00	29.75	31.00	29.50
	10060	29.00	29.00	31.00	28.12	29.00	28.50
	10065	29.25	28.75	30.50	30.25	29.50	32.50
	10066	29.25	32.25	30.50	29.12	33.25	29.50
	10072	30.00	33.75	34.25	29.37	30.75	29.00
	Average,	29.58	30.46	31.46	29.50	30.71	29.79
Reduction of area; per cent.	10027	61.3	61.3	60.6	56.2	54.1	61.2
	10028	63.1	59.7	62.9	58.9	58.3	62.3
	10060	60.1	57.0	60.0	55.9	52.7	57.3
	10065	61.3	58.4	60.6	56.7	55.9	61.6
	10066	61.5	59.9	60.9	54.0	52.5	60.0
	10072	61.3	57.6	61.2	57.4	54.1	61.3
	Average,	61.6	59.0	61.0	56.5	53.8	60.7

in contraction of area may easily be explained, for the determination rests upon accurate measurements of an irregular body. In a bar having an original section of 2" x ⅝", the fractured end will have a thickness of about 0.20 inch, and will be of irregular form, the sides being concave rather than flat. A true estimation of the

broken area could be made only by the most careful duplicate readings and by the aid of the calculus.

The variations in elongation may be partially accounted for by unlike methods of measurement, for if the original punch-marks be put on the outer edge of the bar, they will give a different reading after fracture than if they were put in the center line, owing to the unequal distortion of the bar. This complication would not occur in a round test-piece. The differences in ultimate strength and elastic limit are due in some measure to slight variations in the original measurements of the bar. The elastic limit was found by noting the "drop of the beam," this being the universal practice in American steel works and rolling mills.

The statement that this method is especially inaccurate is open to debate. In Table XVI-V the elongation, as determined by different observers, varies from 29.50 to 31.46 per cent., these figures being in the ratio of 100 to 106.6, or a range of error of 6.6 per cent. The reduction of area varies from 53.8 to 61.6 per cent., a ratio of 100 to 114.5, or a range of error of 14.5 per cent. The elastic ratio varies from 63.2 to 69.1 per cent., a ratio of 100 to 109.3, or a range of error of 9.3 per cent. Thus the determination of the elastic ratio is much more accurate than the results on contraction of area, and nearly as accurate as the results on elongation, both determined by exact measurements made on the piece when at rest. It would be in order for reformers to apply their energies to the accurate determination of the reduction of area and the elongation, instead of trying to substitute a new method for determining the elastic limit, especially when this method has been publicly branded as inaccurate.*

As a rule, the autographic device gives a slightly lower reading than the drop of the beam; thus Gus. C. Henning† gives the determinations of the elastic limit on a series of tests, as found by the two methods. I have averaged the list of heats where both readings are given, and in thirty-eight cases the autographic record was 46.6 per cent. of the ultimate strength, while the beam dropped at 52.9 per cent.; in the annealed bar the first method gave 51.6 per cent., and the second 56.9 per cent. Such a marked difference is not found in all cases, as shown by Table XVI-W, which gives the

* Lewis. *Trans. Am. Soc. Civil Eng.* Vol. XXXIII, p. 351.
† *Trans. Am. Soc. Mech. Eng.*, Vol. XIII, p. 572.

results obtained by E. A. Custer at The Baldwin Locomotive Works. In the case of the slow speed there is less difference between the two determinations of the elastic limit than is shown by Henning, while with the fast speed there is more. The influence of the pulling speed upon the recorded physical properties is considered in the next section.

TABLE XVI-W.

Parallel Determinations of the Elastic Limit by the Autographic Device and by the Drop of the Beam.*

No. of tests.	Pulling speed.	Ultimate strength; pounds per sq. in.	Elastic limit; pounds per square in. as determined by		Elastic ratio; per cent., as determined by	
			Autographic device.	Fall of beam.	Autographic device.	Fall of beam.
6	1 inch in 3 minutes.	56820	36120	37510	63.6	66.0
3	4 inches in 1 minute.	58870	35690	40580	61.0	68.8

The determination of the elastic limit was discussed in *The Engineering News,* of July 25, 1895. After reviewing the arguments presented by several engineers, the following conclusions were reached:

"Having shown the impossibility of determining, by micrometric measurement, the elastic limit, when it is defined as the point at which the rate of stretch begins to change, and the extreme variability of the position of the so-called 'yield-point' with the method of running the machine and with the method of measuring and recording results, had we not better drop these new definitions and methods of attempting to locate points whose position is so extremely variable, and whose determination depends so largely upon the personal equation of the observer, and return to the good, old-fashioned definitions and methods? If, for scientific purposes, there is any need for determining microscopically that point at which the rate of stretch begins microscopically to change, let us call that point the 'limit of proportionality,' as Bauschinger did, and leave its determination to the college professors.

"Let us keep the old term elastic limit with its old significance as that point at which a permanent set visible to the naked eye takes place, at which the rate of stretch increases so that the in-

* From E. A. Custer, Baldwin Locomotive Works, Philadelphia, Pa.

crease may be (albeit with some difficulty) distinguishable by the use of a pair of dividers and a magnifying glass, or more easily and certainly by the drop of the beam, or by the increase in the number of turns of the crank needed to produce a given increase in stretch.

TABLE XVI-X.

Effect of Variations in the Pulling Speed of Testing Machine.

NOTE.—Tests were made by The Pennsylvania Steel Company.

	Number of bars.	Pulling speed; inches per minute.				
		4.50	3.00	0.67	0.38	0.07
Ultimate strength; pounds per square inch.	1	61060	61360	60640	60240	59660
	2	61140	60760	59200	59440	59100
	3	61610	61220	59910	59080	59100
	4	61500	61150	59950	59620	59220
	5	61870	61580	59960	59910	59760
	6	60200	59720	59040	58240	59100
	7	60620	60140	59290	59380	58900
	8	60520	59580	58760	58400	58160
	9	61200	61100	60000	59620	58870
	10	61080	60100	59480	59340	59100
	Av.	61075	60672	59523	59387	59027
Elastic limit; pounds per square inch.	1	46640	44980	42240	42650	39610
	2	44070	43500	44810	41980	39480
	3	46920	44680	42220	41270	39260
	4	46780	45560	42720	41880	40800
	5	45080	46800	43120	43480	40480
	6	44360	43400	41690	40610	39240
	7	47500	43670	43090	41880	39950
	8	44680	44680	42650	41270	39730
	9	45000	43440	42280	40860	39720
	10	46100	43940	43120	41600	39720
	Av.	45708	44410	42904	41763	39647
Elastic ratio; per ct.	Av.	74.84	73.20	72.08	70.32	67.17
Elongation in 8 inches; per cent.	1	29.50	28.25	31.00	28.00	34.00
	2	32.00	30.50	30.75	29.50	31.25
	3	31.75	32.00	27.50	29.25	31.25
	4	27.75	27.00	28.50	28.00	32.25
	5	31.50	30.50	30.00	29.50	30.25
	6	30.50	30.75	29.00	30.00	33.00
	7	29.50	30.50	31.00	31.00	32.75
	8	31.00	28.50	29.25	28.00	33.75
	9	30.00	32.00	28.00	30.00	30.75
	10	29.65	31.75	29.50	30.00	32 00
	Av.	30.32	30.18	29.45	29.33	31.93
Reduction of area; per cent.	1	66.1	65.9	66.7	67.0	68.4
	2	67.1	66.0	66.0	66.7	67.1
	3	62.8	62.4	63.9	63.2	65.4
	4	64.9	65.0	64.9	65.9	67.7
	5	63.2	64.4	64.2	63.7	65.0
	6	66.0	66.2	66.7	67.3	66.0
	7	66.8	66.3	67.4	67.1	67.9
	8	62.4	62.6	63.0	63.1	64.3
	9	64.5	63.5	64.3	65.8	66.9
	10	66.2	66.0	66.1	67.1	67.6
	Av.	64.96	64.88	65.32	65.60	66.48

"For the purpose of determining this elastic limit let the testing machine be run by hand until the limit is passed and the record taken (or run by hand between the load of 30,000 pounds and the elastic limit), and then let the power gear be thrown in and the test completed in the present rapid fashion. Since the term 'yield point' is quite recent, and has no meaning essentially different from the words 'elastic limit' in time-honored practice, why need it be used at all?"

These conclusions represent common sense in their summary dealing with the petty theories of enthusiasts, who are so wrapped up in the accurate determination of a micrometrical measurement that they ignore the more important variations inherent in the method itself, not to mention the still more overwhelming differences caused by changes in the history and shape of the material. I do not see, however, why it is necessary to drive a machine by hand. This is a confession of lack of ingenuity which is not creditable to engineering science.

SEC. XVIn.—*Variations in the pulling speed.*—To find the effect of variations in pulling speed, ten different rivet rods were taken from an acid open-hearth heat. From each rod five bars were cut, and each one was broken at a different speed. Table XVI-X shows that a decrease in pulling speed is accompanied by a decrease in ultimate strength, elastic limit, elastic ratio, and elongation. The differences are not extreme, but their regularity makes the testimony almost conclusive. In the slowest speed there is an exception to this rule in a marked increase of extension, and inspection shows that this does not arise from an average of erratic members, but from an increase in every bar. This point is not of great importance, since it requires nearly an hour to break a bar of steel at this speed. The reduction of area remains practically constant throughout the series. The natural result of this investigation would be a tendency toward higher breaking speeds, but this may be carried too far, since with fast work it is more difficult to take accurate readings.

CHAPTER XVII.

THE INFLUENCE OF CERTAIN ELEMENTS ON THE PHYSICAL PROPERTIES OF STEEL.

Numerous investigations have been conducted to discover the influence of different elements on the strength and ductility of steel, a common method being to melt definite combinations in crucibles and ascribe the physical result to the known variables. This system will discover the effect of large proportions of certain elements, but it is worthless in the accurate valuation of minute proportions of the metalloids, since small variations in the chemical equation are masked by irregularities in casting and working. The problem is also complicated by numberless combinations of different percentages of the various elements, so that it is difficult to obtain groups where there is only one variable. It has, therefore, not infrequently happened that inconclusive data have been joined to bad logic, and the conclusions of investigators have been at variance with the teachings of experience. It is not my purpose to enumerate all the deductions of experimenters, but to give a general survey of the situation. In Part I each element is considered separately, and the views therein advanced are in accord with the general consensus of opinion among metallurgists. Part II gives the result of special investigations into the effect of carbon, manganese, and phosphorus and a determination of the strength of pure iron.

PART I.

EFFECT OF CERTAIN ELEMENTS AS DETERMINED BY GENERAL EXPERIENCE AND BY THE USUAL METHODS OF INVESTIGATION.

SECTION XVIIa.—*Carbon.*—The ordinary steel of commerce is carbon-steel; in other words, the distinctive features of two different grades are due to variations in carbon rather than to differences in other elements. There are often wide variations in manganese,

phosphorus, silicon, etc., but the carbon usually determines the class in which the material belongs. This selection of carbon as the one important variable arose from the fact that primitive Tubal Cains could produce a hard cutting instrument with no apparatus save a wrought-iron bar and a pile of charcoal; and the natural developments in manufacture have led to the conclusion that a given content of carbon will confer greater hardness and strength, with less accompanying brittleness, than any other element.

There are exceptions to this statement in hard steels made by manganese, chromium, or tungsten, but it is true in soft steel. It follows that no limit should be placed to the carbon allowed in structural material if a given tensile strength is specified. Every increment of carbon increases the hardness, the brittleness under shock, and the susceptibility to crack under sudden cooling and heating, while it reduces the elongation and reduction of area, but the strength must be bought at a certain cost, and this cost is less in the case of carbon than with any other element.

SEC. XVIIb.—*Silicon.*—The contradictory testimony concerning the effect of silicon on steel has been summarized by Prof. Howe.* He finds no proof that silicon has any bad effect upon the ductility or toughness of steel, and concludes that the bad quality of certain specimens is not necessarily due to the silicon content. A Bessemer steel with high silicon is sometimes produced by hot blowing, but it is wrong to compare such metal with the common product and ascribe all differences to the chemical formula, rather than to the circumstances which created that formula.

Since the appearance of *The Metallurgy,* an able paper has been written by Hadfield,† who produced alloys with different contents of silicon by melting wrought-iron and ferro-silicon in crucibles. The metal was cast in ingots $2\frac{1}{2}$ inches square, and these were reduced by forging to $1\frac{3}{4}$ inches square and rolled into bars $1\frac{1}{8}$ inches in diameter. In the list of analyses in the paper referred to, there are slight differences in the composition of drillings from different bars of the same ingot, but, in Table XVII-A, I have averaged the results of each cast so as to show the nature of the material under investigation, and have given the physical results on the rolled bars in their natural state.

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* *The Metallurgy of Steel*, p. 36.

† *On Alloys of Iron and Silicon. Journal I. and S. I.*, Vol. II, 1889, p. 222.

TABLE XVII-A.

Physical Properties of Silicon Steels.*

Mark.	Carbon; per cent.	Silicon; per cent.	Manganese; per cent.	Sulphur; per cent.	Phosphorus; per cent.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.	Ultimate strength after annealing; pounds per square inch.
A	.14	.21	.14	.08	.05	78920	49280	66.7	30.05	54.54	56000
B	.18	.77	.21	. . .	. .	76160	56000	73.5	29.50	54.54	64960
C	.19	1.57	.28	. . .	. .	84000	62720	74.7	31.10	50.56	73920
D	.20	2.14	.25	.06	.04	88480	69440	78.5	18.48	28.02	76160
E	.20	2.67	.25	. . .	. .	95200	71680	75.3	17.60	24.26	71680
F	.21	3.40	.29	. . .	. .	106400	78400	73.7	11.10	14.22	87360
G	.25	4.20	.26	. . .	. .	109760	100800	91.8	0.004	0.20	85120
H	.26	5.06	.29	.06	.04	107520	not visible	. . .	0.80	0.70	56000

Bars *A, B, C* and *D* showed a silky fracture after breaking, but with higher silicon the crystallization was very coarse. They also showed no great hardening or brittleness after being quenched in water from a yellow heat, while even the higher alloys, although made quite stiff by the chilling, were not rendered very hard, and preserved a good degree of ductility. With the exception of *A*, the ingots forged well even up to 5.5 per cent. of silicon, but all attempts at welding were unsatisfactory.

These results are of value in showing that silicon cannot be classed among the highly injurious elements, for in similar proportion phosphorus and sulphur would be out of the question, manganese would give a worthless metal, and carbon would change the bar to pig-iron. It will be only reasonable to suppose that small quantities cannot exert a very deleterious influence.

The only bar in the table with a moderate content of silicon is *A* with .21 per cent., and this ingot did not forge well and did not weld, but the manganese was only .14 per cent., while the sulphur was .08 per cent., and the phosphorus .05 per cent. It would hardly be expected that such metal would forge well, and it is not singular that it gave trouble, while other experimenters have forged and welded steel with similar contents of silicon when the associated elements were in proper proportion.

In the whole series the work done upon the ingot in reducing it

* Condensed from Hadfield. *Journal I. and S. I.*, Vol. II, 1889, p. 222.

from $2\frac{1}{2}$ inches square to $1\frac{1}{8}$ inches in diameter was wholly insufficient to give a proper structure, so that little weight can be attached to the determination on any one bar. This renders it difficult to calculate the exact effect of silicon, especially since the bars *A* and *B* present contradictions. Thus *B* contains .04 per cent. more carbon than *A*, .07 per cent. more manganese, and .56 per cent. more silicon, and yet has only 2240 pounds more tensile strength per square inch.

TABLE XVII-B.

Influence of Silicon on the Tensile Strength.

Mark.	Chemical composition; per cent.			Ultimate strength; lbs. per square inch.	Excess of strength over Test B.	Excess of strength over Test B after allowing for difference in carbon; .01 per cent. carbon = 1000 lbs.	Excess in per cent. of silicon over Test B.	Effect of .01 per cent. of silicon, assuming that excess in strength, after allowing for carbon, is due to silicon.
	C	Si	Mn					
B	18	.77	.21	76160	.....	.....	.....	.....
C	19	1.57	.28	84000	7840	6840	0.80	85
D	20	2.14	.25	88480	12320	10320	1.37	75
E	20	2.67	.25	93200	19040	17040	1.90	90
F	21	3.40	.29	106400	30240	27240	2.63	104
G	25	4.30	.38	109760	35600	26600	3.53	75
H	26	5.08	.29	107520	31360	23360	4.31	54

Inspection shows that *A* is probably the erratic member, for its strength is too high for its composition. Moreover, the annealed bars show a loss in strength of 24 per cent. from the natural in *A*, while bars *B*, *C* and *D* give 15, 12 and 14 per cent., respectively, so that it is likely that *A* is finished at too low a temperature and has a higher strength than really belongs to it. For this reason it will be set aside as abnormal, and in Table XVII-B the bar *B* is taken as a basis from which to investigate the differences in tensile strength. No allowance is made for manganese, since this element is fairly constant in all the specimens, but a value of 1000 pounds per square inch is given to carbon, according to the results given in Section XVIIm. After this allowance the remaining variations are ascribed to silicon, but as no data are at hand concerning the content of phosphorus, the answer is open to question.

TABLE XVII-C.

Properties of Steels Containing from .01 to .50 Per Cent. Silicon.*

NOTE.—All bars rolled well; they bent well both hot and cold except No. 11, which broke cold at an angle of 60°; they all welded perfectly; the differences in hardness were scarcely perceptible.

Number of test.	Silicon; per cent.	Carbon; per cent.	Sulphur; per cent.	Phosphorus; per cent.	Manganese; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.	Elongation in 10 inches; per cent.	Reduction of area; per cent.
1	.010	.16	.050	.000	.550	49280	66894	74.3	28.1	48.8
2	.061	.16	.028	.058	.619	49750	70606	70.3	20.4	40.7
3	.070	.15	.084	.051	.500	47152	66102	71.3	22.9	51.5
4	.092	.21	.084	.064	.584	50243	75898	66.6	19.4	44.1
5	.102	.18	.028	.066	.662	47622	75197	63.4	20.6	51.4
6	.121	.19	.064	.068	.576	50848	71857	71.3	21.9	48.7
7	.315	.13	.028	.057	.490	47690	65901	72.4	24.8	56.6
8	.347	.19	.028	.074	.642	49795	77728	64.0	17.6	49.6
9	.320	.15	.040	.081	.490	49997	74495	67.1	16.7	36.1
10	.382	.16	.042	.067	.588	55873	79001	69.3	18.0	30.7
11	.504	.18	.094	.121	.455	59024	82258	71.7	19.4	34.8

This table cannot be called conclusive, for the carbon was determined by color instead of combustion, the number of tests is altogether too limited, and no account is taken of phosphorus, but there seems to be a strengthening effect of about 80 pounds for every .01 per cent. of silicon up to a content of 4 per cent., while beyond this there is a deterioration of the metal, as shown in Table XVII-A. This would mean an increase of only 1600 pounds for .20 per cent. silicon, being one-third more than that produced by .01 per cent. of carbon. (See Table XVII-U.) It has been noted that *A*, which was the only bar containing an ordinary percentage of silicon, gave abnormal results in tensile strength, but this cannot be due to silicon, for the elastic ratio is normal, the elongation fair, and the reduction of area good.

An investigation into the effect of ordinary proportions of silicon was conducted by Turner, and Table XVII-C gives the results as published in *Journal I. and S. I.*, Vol. II, 1888, p. 302. There are variations in the elements other than silicon, and the bad character of No. 11 may be explained by its high content of phosphorus. For better comparison Table XVII-D gives the averages of the

* Report of British Association, 1888.

first four tests, all of which are below .10 per cent. in silicon, and the last three, which are above .30 per cent.

TABLE XVII-D.

Physical Properties of Low-Silicon and High-Silicon Steels.

Group.	Number of heats in group.	Composition; per cent.					Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.	Elongation in 10 inches; per cent.	Reduction of area; per cent.
		Si.	C.	S.	P.	Mn.					
1	4	.056	.170	.061	.058	.576	49106	69675	70.5	21.5	46.3
2	3	.402	.160	.059	.096	.493	54798	78863	69.5	18.0	33.9

The effect caused by elements other than silicon may be calculated, carbon being taken at 1000 pounds for .01 per cent., and phosphorus at 1000. The result is as follows:

	Lbs. per sq. in.
Group II should be stronger than Group I.	
On account of phosphorus, 3.8×1000	3800
Group II should be weaker than Group I.	
On account of carbon, 1×1000	1000
Net strengthening from constituents other than silicon	2800
Strengthening from all constituents including silicon	9188
Strengthening due to .35 per cent. of silicon	6388
Strengthening due to each .01 per cent. of silicon	183

This signifies that .20 per cent. of silicon would give an increase in strength of 3700 pounds per square inch, which is less than would be given by .04 per cent. of carbon.

The influence of silicon upon the tensile strength is often confounded with that of carbon. It is well known that the addition of high-silicon pig-iron to a charge of low steel strengthens the metal more than a similar addition of ordinary pig-iron. But the fact is lost sight of that this silicon prevents the burning of carbon, both by the absorption of oxygen and by the deadening of the bath, so that the resultant metal is of higher carbon.

If the ordinary color method were reliable, this would be detected and proper credit given to it, but often an increment of .03 per cent. of carbon is not shown by analysis, so that its effect upon the strength, which will amount to 3000 pounds per square inch, will

be incorrectly ascribed to whatever small percentage of silicon has survived the reactions during recarburization. This criticism on the determination of carbon applies to the data given in Tables XVII-A and XVII-C, and renders the calculations thereon of limited value.

Many continental works have habitually made rails with from .30 to .60 per cent. of silicon, and all requirements of strength and ductility have been met. All the authorities do not approve this practice, and it is stated by Ehrenwerth* that the latest results are rather in the opposite direction in the case of low steels,† but I was told some years ago, by the manager of one of the French establishments, that the only way in which he was able to fill one contract with particularly severe specifications was by making the rails contain from .30 to .40 per cent. of silicon, since a less proportion would not stand the drop-tests. It is not necessary to question whether this conclusion was warranted or not; it is enough to know that the steel was of the best quality, whether on account of the silicon or in spite of it.

Silicon is allowed in rails by Sandberg, who writes as follows:‡ "Silicon up to .30 per cent., with carbon .30 to .40 per cent., does not harden steel or make it brittle, and *diminishes its strength in such small degree* as not to imperil the safety of the rail." The italics are my own, and call attention to the implication that silicon lowers the strength rather than raises it. Exceptional cases have been recorded of soft steels with high silicon, like the tough rail mentioned by Snelus,§ with carbon below .10 per cent. and silicon .83 per cent. It must be considered, however, that although this might have been very tough for a rail, it does not follow that it was very tough for soft steel, but it is quite certain that it could not have been bad or brittle.

Knowing the relative effect of impurities upon hard and soft steels, the assumption would be justified that low-carbon metal could contain a larger percentage of silicon than higher steel, but structural steels do not often contain over .05 per cent. of silicon, while usually they hold less than .03 per cent. Tool steel is sub-

* *Das Berg- und Hüttenwesen auf der Weltausstellung in Chicago*, 1895.

† See page 78, *ante*.

‡ *Proc. English Inst. Mech. Eng.*, 1890, p. 301.

§ *On the Chemical Composition and Testing of Steel Rails. Journal I. and S. I.*, Vol. II, 1882, p. 583.

jected to the most severe of all tests in the exposure of a hardened edge to the blows of a hammer or the shocks of a planer. The requirements of general practice unconsciously evolved the formula for such metal, requiring low phosphorus, low sulphur and low manganese. In this process of natural selection no mention was made of silicon. Some makers try to keep it as low as possible, but a large part of the best steel has regularly contained, year after year, from .20 to .80 per cent. of this element.

Notwithstanding all this testimony, it is firmly believed by many practical metallurgists that the presence of even .03 per cent. materially injures the quality of soft steel. I cannot positively assert the contrary, but I believe that the effects ascribed to silicon may be due to the conditions of manufacture which gave rise to it. These conditions might be fatal under one practice, as, for instance, when ingots are rolled directly into plates, while they might be harmless, or even beneficent, when an ingot is roughed down and reheated. The opinions of practical men are sometimes of more value than the learned conclusions of theorists, and must never be ignored, but they are not always inerrant.

SEC. XVIIc.—*Influence of manganese.*—Spiegel-iron or ferro-manganese is added to a heat of steel at the time of tapping in order that it may seize the oxygen, which is dissolved in the bath, and transfer it to the slag as oxide of manganese; but this reaction is not perfect, and there is reason to believe that common steels contain a certain percentage of oxygen. Steel low in phosphorus and sulphur requires less manganese than impure metal, although it is difficult to see why there should be less oxygen to counteract, and this indicates that the manganese prevents the coarse crystallization which the impurities would otherwise induce.

Besides conferring the quality of hot ductility, manganese also raises the critical temperature to which it is safe to heat the steel, for just as it resists the separation of the crystals in cooling from a liquid, so it opposes their formation when a high thermal altitude augments the molecular mobility. These two qualities render manganese one of the most valuable factors in the making of steel, although it has been used too freely in some cases. Years ago it was regarded as a panacea for all bad practices in the Bessemer and the rolling mill, and steel often contained from 1.25 to 2 per cent. of manganese, but it was soon discovered that such rails were brittle

under shock, so that the permissible maximum has been gradually lowered, and the standard product of the present day contains from .70 to 1 per cent. In higher steels the same lesson has been learned, but in this case the necessity of a low content is far more marked, since a percentage which is perfectly harmless in unhardened steel will cause cracking if the metal be quenched in water.

In structural metal there is no quenching to be done and the line of maximum manganese need not be drawn too low. It is more convenient to produce a higher tensile strength by the use of spiegel-iron than with ordinary pig-iron, since manganese deadens the metal and prevents the oxidation of the carbon. Thus an increased strength resulting from the addition of more recarburizer is usually accompanied by an increase in the manganese, and it is currently assumed that a considerable part of the extra strength is due to the higher percentage of this element. In great measure this is an error, for the increase in carbon is often sufficient to account for the change.

Ferro-manganese containing 80 per cent. of manganese holds about 5 per cent. of carbon, and since one-third of the manganese is lost during the reaction while very little carbon is burned, it follows that $\frac{2}{3}\times 80=53$ points of manganese will be added to the steel for every 5 points of carbon. Thus, if the content of manganese in any heat be raised .20 per cent. by an increase in the recarburizer, there will at the same time be an increment of .02 per cent. of carbon. This slight change in carbon will not always be detected by the color method, particularly as an increase in manganese interferes with the accuracy of the comparison by altering the tint of the solution, and so the effect of this carbon, representing an increase in strength of 2400 pounds per square inch, is often ascribed to the increment of manganese. It is necessary, therefore, to compare steels where the composition is thoroughly known, to find the effect of this element.

It is currently believed that manganese reduces the ductility of steel, but Table XVII-E will show that the effect is not well marked. This table is made by grouping heats of the same general character and of about the same strength, and separating them into two classes according to their manganese content. No arbitrary line is drawn between a high and low percentage, but each group is divided so

that the number is as nearly equal as possible on each side. An unequal number is due solely to the fact that several heats have the same content, and these must all be placed either on one or the other side of the line.

TABLE XVII-E.

Properties with Different Contents of Manganese.

Made by The Pennsylvania Steel Company.

Group.	Kind of steel.	Limits of ultimate strength in group; pounds per square inch.	Phosphorus; per cent.	Relative manganese.	Number of heats.	Manganese; per cent.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.	Shape of test; in inches.
I	Acid	55000 to 60000	.08	Low High	7 6	.30 .37	57922 58981	38602 38508	29.91 28.08	59.02 57.07	66.8 65.6	¾ diam.
II	Basic	55000 to 60000	.08	Low High	11 11	.44 .57	58005 59563	38547 40133	30.16 30.36	60.21 58.55	66.5 67.4	2x¾
III	Acid	60000 to 65000	.08	Low High	16 14	.35 .51	62180 62605	41308 41169	28.00 27.65	50.89 54.66	66.4 65.8	¾ diam.
IV	Acid	65000 to 70000	.08	Low High	26 32	.51 .78	67421 68192	43923 45854	25.96 25.82	51.29 51.50	65.1 67.2	¾ diam.
V	Acid	70000 to 75000	.08	Low High	18 25	.60 .91	72358 72115	46936 48359	24.23 24.63	47.79 47.73	64.7 67.1	¾ diam.
VI	Acid	75000 to 80000	.08	Low High	11 11	.65 .84	77520 78088	49411 50236	22.34 23.63	44.42 48.49	63.7 64.3	¾ diam.
VII	Acid	80000 to 85000	.08	Low High	9 9	.68 .82	81747 81860	51219 52281	20.63 22.67	41.04 47.75	62.7 63.8	¾ diam.
VIII	Acid	85000 to 90000	.08	Low High	5 5	.75 .88	86460 88084	54517 55409	20.41 20.66	40.56 41.92	63.1 62.9	¾ diam.

There is no marked difference between the steels of high and low manganese, and the eight different groups are so uniform that the work of chance must be almost absent. These records, however, do not take into account the important quality of resistance to shock. It has always been a problem to devise a satisfactory test in this direction, but the method is yet to be found. A few crude experiments which I performed on steel of high manganese, to see how it would act under shock, are given in Table XVII-F. The bar was struck while in tension with a copper hammer, each blow being powerful enough to have permanently bent the bar if it had not been continually straightened by the action of the machine. One of the effects of this hammering is to momentarily loosen the

bar in the grips and make a sudden jar upon the piece. This action, coupled with the stress upon the outside fibers and the direct vibration, makes the test quite exhaustive, although from the difficulty

TABLE XVII-F.

Resistance to Shock of Steel Containing about 1 Per Cent. of Manganese.

All tests ¾-inch rolled rounds, made by The Pennsylvania Steel Company.

Heat number.	Manganese; per cent.	Conditions under which test was made.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
6960	1.00	Average of two tests, pulled quietly	71040	47055	25.87	55.05
		Average of two, hammered from start to finish	70770	46980	26.12	61.40
6961	1.08	Average of two tests, pulled quietly	72175	48075	27.00	54.98
		Average of two, hammered from start to finish	71120	47880	26.00	59.20
6962	0.94	Average of two tests, pulled quietly	74020	48165	25.62	52.60
		Average of two, hammered from start to finish	74490	48340	28.50	55.70
6963	1.18	One bar, pulled quietly	81070	52980	22.50	48.00
		One bar, hammered from elastic limit to fracture	80460	52760	23.50	48.80
		One bar, hammered from failure to fracture,	78050	51800	19.25	55.80
		One bar, began hammering at 72000 pounds, and moved scale weight back as the bar weakened	69040	52760	21.00	47.80
6981	0.82	One bar, pulled quietly	67340	46080	23.12	55.00
		One bar, hammered from failure to fracture,	65940	44480	23.00	57.90
6982	0.91	One bar, pulled quietly	66700	46310	26.00	55.98
		One bar, hammered from failure to fracture,	67240	46090	31.25	55.60
6983	1.06	One bar, pulled quietly	69700	47650	26.00	51.70
		One bar, hammered from failure to fracture,	70080	46960	27.12	58.70

of measuring the force of impact it can hardly be called practical. Some of the bars were not struck until "failure," or until the maximum stress had been reached. This was on account of the slipping or jumping above noted which followed the hammering at earlier periods, and it was taken for granted that if a bar would break at all from shock, the fracture would be likely to occur about the time when the piece was under destructive tension. The hammering did not in any case determine the time of breakage, for each piece gave as good an elongation and reduction of area as a

part of the same rod pulled in the usual manner. It is not the intention to advocate the use of such a high content of manganese, for the general conclusion of metallurgists points to as low a proportion as will ensure good working in the rolls. In the case of ingots rolled directly into plates, the allowable content is limited by the requirement that the steel shall boil in the molds, but it does not follow, because bad results accompany higher manganese in such practice, that the quality of the product is proportionally deteriorated when the ingot is roughed down and reheated.

The effect of large proportions of manganese upon steel is one of the most curious phenomena in metallurgy. As the content rises over 1.5 or 2 per cent. the metal becomes brittle and almost worthless, and further additions do not better the matter until an alloy is reached with about 6 or 7 per cent. manganese. From this point the metal is not only extremely hard, but possesses the rather peculiar property of becoming very much tougher after quenching in water, without any great change in hardness. The physical properties of manganese steel are shown in Table XVII-G, which is taken from an article by Hadfield.* This alloy is used in the making of

TABLE XVII-G.

Forged Steel Containing from .83 to 19 Per Cent. Manganese.†

No. of sample.	Composition; per cent.			Natural.		Quenched in water.		Annealed.	
	Carbon.	Silicon.	Manganese.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.
1	.20	.08	.83	73920	31	. . . . .	. . . .	. . . . .	. . . .
2	.40	.15	2.30	125440	6	. . . . .	. . . .	. . . . .	. . . .
3	.40	.09	3.89	85120	1	. . . . .	. . . .	. . . . .	. . . .
4	.52	.37	6.95	56000	2	51520	2	47040	2
5	.47	.44	7.22	60480	2	56000	2	60480	5
6	.61	.30	9.37	73920	5	87360	15	85120	16
7	.85	.28	10.60	76160	4	89600	17	91840	17
8	1.10	.16	12.60	87360	2	120960	27	89880	11
9	.92	.42	12.81	87360	5	136640	37	107520	20
10	.85	.28	14.01	80640	2	150080	44	107520	14
11	1.10	.32	14.48	87360	1	141120	37	109760	5
12	1.24	.16	15.06	109760	2	136640	31	105280	2
13	1.54	.16	18.40	114240	1	118720	10	87360	1
14	1.88	.26	18.55	96320	1	123200	5	. . . . .	. . .
15	1.60	.38	19.10	116480	1	132160	4	91840	1

* See also *The Mineral Industry*, Vol. IV, for an essay on Alloys of Iron, by R. A. Hadfield.

† Condensed from Hadfield, *Journal I. and S. I.*, Vol. II, 1888, p. 70.

car wheels, dredger links and pins, and other articles where the maximum of hardness must be combined with toughness. Its great disadvantage is the difficulty of doing machine work upon it, for the best of hardened tools will rapidly crumble and wear out. In cases where finishing is essential it is necessary to grind by emery wheels.

SEC. XVIId.—*Influence of sulphur.*—Nothing is better established than the fact that sulphur injures the rolling qualities of steel, causing it to crack and tear, and lessening its capacity to weld. The critical content at which the metal ceases to be malleable and weldable varies with every steel. It is lower with each increment of copper, higher with each unit of manganese, and lower in steel which has been cast too hot. In the making of steel for simple shapes, a content of .10 per cent. is possible, and may be exceeded if care be taken in the heating, but for rails and other shapes having thin flanges it is advantageous to have less than .08 per cent., while every decrease below this point is seen in a reduced number of defective bars. It is impossible to pick out two steels with different contents of sulphur and say that the influence of a certain minute quantity can be detected, but it is none the less true that the effect of an increase or decrease of .01 per cent. will show itself in the long run, while each .03 per cent. will write its history so that he who runs may read.

The effect of sulphur upon the cold properties of steel has not been accurately determined, but it is certain that it is unimportant. In common practice the content varies from .02 to .10 per cent., and within these limits it has no appreciable influence upon the elastic ratio, the elongation, or the reduction of area. It is more difficult to say that it does not alter the tensile strength, for a change of one thousand pounds per square inch can be caused by many things. Webster* has stated that sulphur probably increases the ultimate strength at the rate of 500 pounds per square inch for every .01 per cent., but I am inclined to think his conclusion is not founded on sufficient premises. In rivets, eye-bars and firebox steel, the presence of sulphur is objectionable, for it creates a coarse crystallization when the metal is heated to a high temperature, and reduces the toughness of the steel. In other forms of

* *Further Observations on the Relations between the Chemical Constitution and Physical Character of Steel. Trans. A. I. M. E.*, Vol. XXIII, p. 113.

structural material the effect of this element is of little importance.

SEC. XVIIe.—*Influence of phosphorus.*—Of all the elements that are commonly found in steel, phosphorus is the most undesirable. In ordinary proportions its influence is not felt in a marked degree in the rolling mill, for it has no disastrous effect upon the toughness of red-hot metal when the content does not exceed .15 per cent. Its action upon finished material may not be dismissed in so few words. Prof. Howe* has gathered together the observations of different investigators, and the evidence seems to prove that the tensile strength is increased by each increment of phosphorus up to a content of .12 per cent., but that beyond this point the metal is weakened. Below this point it is certain that phosphorus strengthens lows steels, both acid and basic. The same certainty does not pertain to any other effect of this metalloid. Prof. Howe† has discussed the whole matter, and I make quotations from *The Metallurgy of Steel,* in the form of a summary.

(1) The effect of phosphorus on the elastic ratio, as on elongation and contraction, is very capricious.

(2) Phosphoric steels are liable to break under very slight tensile stress if suddenly or vibratorily applied.

(3) Phosphorus diminishes the ductility of steel under a gradually applied load as measured by its elongation, contraction and elastic ratio when ruptured in an ordinary testing machine, but it diminishes its toughness under shock to a still greater degree, and this it is that unfits phosphoric steels for most purposes.

(4) The effect of phosphorus on static ductility appears to be very capricious, for we find many cases of highly phosphoric steel which show excellent elongation, contraction and even fair elastic ratio, while side by side with them are others produced under apparently identical conditions but statically brittle.

(5) If any relation between composition and physical properties is established by experience, it is that of phosphorus in making steel brittle under shock; and it appears reasonably certain, though exact data sufficing to demonstrate it are not at hand, that phosphoric steels are liable to be very brittle under shock, even though they may be tolerably ductile statically. The effects of phosphorus

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* *The Metallurgy of Steel*, p. 67, *et seq.* † *Loc. cit.*

on shock-resisting power, though probably more constant than its effects on static ductility, are still decidedly capricious.

The difficulty of detecting a high content of phosphorus by the ordinary system of physical tests will be shown by Table XVII-H, which is constructed by comparing the acid open-hearth angles in Table XIV-H, which are of the same ultimate strength and of the same thickness, but which contain different percentages of phosphorus. The higher phosphorus gives a higher elastic ratio

TABLE XVII-H.

Properties of Low-Phosphorus and High-Phosphorus Steels.

Limits of ultimate strength; lbs. per square inch.	No. of group.	Thickness of angle; in inches	Phosphorus; per cent.	Number of heats.	Average ultimate strength; lbs. per sq. in.	Average elastic limit; lbs. per sq. inch.	Average elastic ratio; per cent.	Average elongation in 8 in.; per cent.	Average reduction of area; per cent.
56000 to 64000	I	$\frac{5}{16}$ to $\frac{3}{4}$	.05 to .07	212	60845	40891	67.21	29.85	57.4
			.07 to .10	50	60064	41143	68.50	28.82	58.4
	II	$\frac{5}{16}$ to $\frac{1}{2}$	.05 to .07	126	60095	39415	64.94	29.23	55.6
			.07 to .10	50	60583	40170	66.30	29.05	56.3
	III	$\frac{5}{16}$ to $\frac{3}{4}$	.05 to .07	81	60556	38645	63.81	28.95	53.3
			.07 to .10	50	61049	39656	64.96	28.98	54.3
	IV	$\frac{1}{2}$ to $\frac{3}{4}$	.05 to .07	121	59906	37478	62.56	29.32	51.3
			.07 to .10	50	59768	38338	64.15	29.60	55.3
64000 to 72000	V	$\frac{5}{16}$ to $\frac{3}{4}$	.05 to .07	40	65656	42713	66.58	27.90	55.0
			.07 to .10	25	66365	44486	67.08	27.19	55.4
	VI	$\frac{5}{16}$ to $\frac{1}{2}$	.05 to .07	29	65631	42191	64.28	27.83	53.7
			.07 to .10	39	66777	42817	65.09	27.49	53.2

in all six groups, the difference ranging from 0.45 per cent. to 1.59 per cent., but the elongation and the reduction of area are the same in the two kinds of steel. It is the difference between static and shock ductility that makes phosphoric steel so dangerous. In the ordinary testing machine there is no important difference between a pure steel containing less than .04 per cent. of phosphorus, and a common steel with .08 per cent., or a bad steel with .10 per cent.

Constructive engineers and metallurgists have staked and lost their reputations in promoting processes designed to make good material out of steel containing high phosphorus. Many a time such metal has shown high ductility in the testing machine, but each time the high-phosphorus metal has given lamentable failures

as soon as it went beyond the watchful care of its parents and its nurses. Numerous cases can be cited of rails, plates, etc., containing from .10 to .35 per cent. of phosphorus, which have withstood a long lifetime of wear and adversity; but in the general use of such metal there has been such a large percentage of mysterious breakages that it seems quite well proven that the phosphorus and the mystery are the same.

Much information on the effect of phosphorus may be gathered from a study of high steels. A severe trial is put upon a cold-chisel or similar tool, and it is undeniable that each increment of phosphorus has its effect in rendering such a tool brittle. In this case the steel is quenched and it contains a considerable proportion of carbon, but there is no evidence to show that the effect of phosphorus is different when the carbon is high, even though it is more marked. Neither is there reason to suppose that quenching changes its nature, for with high-phosphorus steel of low carbon sudden cooling would rather counteract the influence of phosphorus than enhance it, since it tends to prevent the formation of coarse crystals.

It would seem, therefore, that the regularly increasing banefulness of phosphorus as the carbon is raised does not portray any change in nature, but that, although the effect of the metalloid in lower steels is obscured, its character is the same. No line can be drawn that can be called the limit of safety, since no practical test has ever been devised which completely represents the effect of incessant tremor. For common structural material the critical content has been placed at .10 per cent. by general consent, but this is altogether too high for railroad bridge work. All that can be said is that when all other things are equal safety increases as phosphorus decreases, and the engineer may calculate just how much he is willing to pay for greater protection from accident.

SEC. XVIIf.—*Influence of copper.*—The iron made from the ores of Cornwall, Pa., contains from .75 to 1 per cent. of copper, and large quantities of rails have been made from this iron alone, but it has oftener been the custom at Eastern steel works to use from 25 to 50 per cent. of this iron in the mixture. Other deposits contain considerable quantities of this element, notably some beds in Virginia, while the ores of Cuba give an iron with about .10 per cent. of copper. Most of the Bessemer steels recorded in this book contain from .30 to .50 per cent. of copper, while much of the open-

hearth steel is of the same character, and this will be sufficient proof that the best of steel may contain a considerable proportion. If, therefore, it appears from a set of experiments that copper exerts a bad effect, then one of two things follows:

(1) The experiments have left some factor out of the question.

(2) The maker of good steel has some trick by which he overcomes the enemy.

It would be a cause for satisfaction if we could boast that the latter supposition were true, but we have never known that copper injured the cold properties of steel in any way, and no system has been devised to obviate its influence. Hard and soft steels of our manufacture have found their way into all channels of trade, and although many failures have come, as they have everywhere, from high carbon, high manganese, or high phosphorus, there have been no cases where it was necessary to invoke the aid of copper. This fact outranks and transcends in value any limited series of tests that might be given. In the same way there is no evidence that copper segregates, experience pointing rather to perfect uniformity.

Steel may contain up to one per cent. of copper without being seriously affected, but if at the same time the sulphur is high, say .08 to .10 per cent., the cumulative effect is too great for molecular cohesion at high temperatures and it cracks in rolling. This tearing occurs almost entirely in the first passes of the ingot, so that it is of little importance to the engineer who is concerned only with perfect finished material. In the purest of soft steels containing not more than .04 per cent. of either phosphorus or sulphur, the influence of even .10 per cent. of copper may be detected in the less ready welding of seams during the process of rolling, but ordinarily when the sulphur is below .05 per cent. the copper injures the rolling quality very little, even in the proportion of .75 per cent. In all cases the cold properties seem to be unaffected.

The only facts ever brought out against copper, as far as I am aware, are in a paper by Stead,* who shows that steels containing from 0.46 to 2 per cent. of copper do not give good results in drawn wire when a high percentage of carbon is also present, but it is stated that there is nothing to show that rails or plates are affected injuriously.

The quantitative effect of copper upon the tensile strength was

* *Jour. I. and S. I.*, Vol. II, 1901, p. 122.

the subject of a paper by Ball and Wingham,* in which they showed that as much as 7 per cent. could be alloyed to iron, and that a specimen with 4 per cent. forged well both hot and cold. It was found that the alloys were very hard, so that when the content was over 7 per cent. the metal could not be cut by a good tool. The experiments showed a considerable increase in tensile strength in the case of higher copper, but no great weight can be given to the determinations, for the methods used in making the alloy and in cutting the tests were too crude for conclusive results.

It is not easy to make a comparison between the ductility of high-copper and low-copper steels, for at works using such material it is customary to keep a fairly constant percentage in the mixture rather than to vary between wide limits. A limited number of heats have been grouped together in Table XVII-I, and although the list is not as long as might be desired, it should be considered

TABLE XVII-I.

Properties of Low-Copper and High-Copper Angles.

Made by The Pennsylvania Steel Company, 1896.

Thickness in inches.	Copper; per cent.	Number of heats.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
¾	.10	11	61376	44152	27.52	56.80	71.9
	.35	17	60288	43841	27.88	59.01	72.7
⅞	.10	10	58965	42218	28.85	55.50	71.6
	.35	11	59680	43478	29.02	57.86	72.9

that the heats were all made within a short period in the same Bessemer, and were all rolled in the same mill. No difference is to be found in the ultimate strength between steels with high and low copper, although all the heats were made in the same way as nearly as possible, the workmen not knowing either in the Bessemer department or in the rolling mill what kind of iron was in use.

The high copper gives a slightly higher elastic ratio, which is a benefit, and a better elongation and reduction of area. These re-

* *On the Influence of Copper on the Tensile Strength of Steel. Journal I. and S. I.*, Vol. I, 1889, p. 123.

sults can hardly be called conclusive, for the number of heats is too limited, but as the data on high-copper steels are uniform with the much larger number of similar angles given in Table XIV-H, and as the two separate averages for low copper correspond so closely to one another after allowance is made for the different thicknesses, it seems that the high copper is not in any way harmful.

A notable investigation into the effect of copper was conducted by Mr. A. L. Colby at the Bethlehem Steel Works, and was described in *The Iron Age*, November 30, 1899. Steel containing 0.57 per cent. of copper was forged into crank shafts for the United States battleships and stood every test required by the Government specifications. Another ingot was forged into gun tubes for 6-inch guns for the United States Navy, and fulfilled every requirement of the department. Other exhaustive tests were made on plates and all the results pointed the same way.

SEC. XVIIg.—*Influence of aluminum.*—It is hardly necessary to discuss at length the effect of aluminum upon steel, for although it is often used to quiet the metal, it unites with the oxygen of the bath and passes into the slag. Sometimes a very small percentage remains in steel castings, while it is quite conceivable that other steels may receive a small overdose by mistake, so that Table

TABLE XVII-J.

Physical Properties of Aluminum Steel.

NOTE.—Size of bars ½ x ¾ inch; all samples forged either very well or fairly well except No. 10 which was very shelly. The fractures from Nos. 1 to 7, inclusive, were granular, but Nos. 8, 9, and 10 showed increasing coarse crystallization. All bars bent double cold after annealing except No. 10. Attempts at welding were unsuccessful on samples Nos. 3, 5, and 8.

Group.	Composition; per cent.						Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 2 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
	C.	Si.	S.	P.	Mn.	Al.					
1	.22	.09	. . .	. . .	.07	.15	47040	64960	26.70	62.9	72.4
2	.15	.18	.10	.04	.18	.38	51520	67200	27.85	58.18	76.7
3	.20	.12	. . .	. . .	.11	.61	48160	62720	28.40	54.50	76.8
4	.18	.16	.09	.08	.14	.66	45920	64960	28.85	49.86	70.7
5	.17	.10	. . .	. . .	.18	.72	49280	62720	40.00	60.74	78.6
6	.26	.15	.08	.04	.11	1.16	51520	73920	32.05	51.46	69.7
7	.21	.18	. . .	. . .	.18	1.60	44800	69440	32.70	52.14	64.5
8	.21	.18	.09	.08	.18	2.20	47040	69440	22.75	27.80	67.7
9	.24	.18	. . .	. . .	.32	2.24	48160	72800	20.67	24 64	66 1
10	.22	.20	.08	.08	.22	5.60	. . . . .	85120	3.67	3 96	. . . .

XVII-J will be of interest as giving the results of an investigation by Hadfield.* After making allowances for variations in other elements, it will be found that aluminum has little effect upon the tensile strength, while it does not materially injure the ductility until a content of 2 per cent. is reached.

These conclusions do not agree with the results which I have found by casting different alloys in 6-inch square ingots. The aluminum was added in a solid state and possibly was not disseminated uniformly, but the analysis was made on the test-bar itself, and the fusible nature of the metal makes it probable that the piece would be reasonably homogeneous. Either two or three ingots were cast from each heat, the first containing either no aluminum or only a trace, while the others were made so as to give fairly rich alloys. The results are given in Table XVII-K.

The casting and working of such ingots is a regular operation at the works where these experiments were made, and perfect uniformity is always obtained in respect to tensile strength, so that it is probable the variations in bars of the same heat are due to the different contents of aluminum. These changes are as follows:

(1) The addition of one-half of 1 per cent. of aluminum increases the tensile strength between 3000 and 8000 pounds per square inch, exalts the elastic limit in about the same proportion, and injures very materially the elongation and contraction of area. The effect both upon strength and ductility is more marked in the case of low than in high steels.

(2) The addition of another half of 1 per cent. does not have much effect upon the ultimate strength or the elastic limit, but it still further decreases the ductility of the metal.

It is stated by Odelstjerna† that the use of aluminum, in the manufacture of steel castings, gives an inferior metal, even though the addition amount to only .002 per cent., and that such steel presents a peculiar fracture, the faces of the crystals being large and well defined. It must be kept in mind, however, that these conclusions apply to one particular kind of practice, and that the use of aluminum, under certain conditions, may produce a most

* *Aluminum Steel. Journal I. and S. I.*, Vol. II, 1890, p. 161.

†*The Manufacture of Open-Hearth Steel in Sweden. Trans. A. I. M. E.*, Vol. XXIV, p. 312.

harmful effect, while under other possible conditions the result would be less marked.

SEC. XVIIh.—*Influence of arsenic.*—The effect of arsenic upon steel was investigated several years ago by Harbord and Tucker.* Their conclusions may be summarized as follows:

Arsenic, in percentages not exceeding .17, does not affect the bending properties at ordinary temperatures, but above this per-

TABLE XVII-K.

Effect of Aluminum upon the Physical Properties of Steel.

6-inch square ingots, made by The Pennsylvania Steel Company, rolled to 2x⅝ inch.

	Heat number.	Composition; per cent.						Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Reduction of area; per cent.
		C.	P.	Si.	Mn.	S.	Al.					
Soft basic open-hearth steels.	1791	.11	.024	. . .	.48	.065	.00	48800	38190	68.0	31.25	48.6
		.11	.022	. . .	.45	.085	.58	56880	41150	72.4	18.25	29.8
	1792	.11	.010	. . .	.45	.019	.00	46440	31640	68.1	30.00	49.9
		.11	.011	. . .	.41	.023	.45	58440	36900	69.1	22.50	31.5
	1703	.11	.013	. . .	.35	. . .	.00	47160	33490	71.0	31.25	45.8
		.11	. . .	. . .	. . .	. . .	.50	53900	38580	71.5	27.00	33.7
Soft acid open-hearth steels.	3681	.17	.035	. . .	.61	.025	.04	58560	39810	67.1	30.00	45.7
		.16	. . .	. . .	. . .	. . .	.473	63440	42100	66.4	23.00	36.2
		.14	. . .	. . .	. . .	. . .	.899	64160	39100	60.9	17.50	25.4
	3686	.14	.059	. . .	.58	.021	.03	65080	43260	66.5	24.00	46.2
		.14	. . .	. . .	. . .	. . .	.46	67810	47950	70 7	20.00	34.0
		.12	. . .	. . .	. . .	. . .	1.171	67420	48850	72.5	8.00	15.0
	3688	.12	.034	. . .	.51	.021	.013	55700	39550	71.0	28.7	51.8
		.12	. . .	. . .	. . .	. . .	.45	59880	39100	65.3	21.7	40.5
		.13	. . .	. . .	. . .	. . .	.80	61470	43710	71.1	21.2	34.2
Hard acid open-hearth steels.	3682	.47	.048	.21	.70	.018	.00	107450	65980	61.4	10.0	20.1
		.44	. . .	. . .	. . .	. . .	.571	110550	72420	65.5	9.2	17.5
		.43	. . .	. . .	. . .	. . .	1.135	105100	68080	64.8	12.5	21.0
	3683	.54	.044	.31	.75	.020	.00	124040	47880	38.6	10.0	18.0
		.47	. . .	. . .	. . .	. . .	.37	122080	47680	39.1	. . .	8.2
		.43	. . .	. . .	. . .	. . .	.94	128040	47440	37.0	7.5	9.4
	3684	.40	.040	.26	.67	.028	.01	95010	42740	45.0	18.7	41.0
		.36	. . .	. . .	. . .	. . .	.54	98875	43050	43.8	14.0	34.5
		.38	. . .	. . .	. . .	. . .	.90	98720	43150	43.7	12.5	20.4
	3685	.40	.046	.30	.68	.031	.00	94700	44610	47.1	16.2	31.3
		.38	. . .	. . .	. . .	. . .	.52	100055	47240	47.2	18.7	34.1
		.34	. . .	. . .	. . .	. . .	.78	98480	46910	47.6	12.5	17.5
	3689	.42	.046	.21	.71	.025	.00	90900	58550	58.9	15.5	22.0
		.40	. . .	. . .	. . .	. . .	.31	94560	59190	62.6	15.0	29.7
		.34	. . .	. . .	. . .	. . .	.56	96680	59460	61.5	14.7	25.4

* *On the Effect of Arsenic on Mild Steel. Journal I. and S. I.*, Vol. I., 1888, p. 183.

centage cold-shortness rapidly increases. In amounts not exceeding .66 per cent., the tensile strength is raised considerably. It lowers the elastic limit, and decreases the elongation and reduction of area in a marked degree. It makes the steel harden more in quenching, and injures its welding power even when only .093 per cent. is present.

These results have been corroborated by J. E. Stead,* who found that between .10 and .15 per cent. of arsenic in structural steel has no effect upon the mechanical properties; the tenacity is but slightly increased, the elongation and reduction of area unaffected. With .20 per cent. of arsenic, the difference is noticeable, while with larger amounts the effect is decisive. When one per cent. is present, the tenacity is increased, and the elongation and reduction of area both reduced. This increase in strength and diminution in toughness continue as the content of arsenic is raised to 4 per cent., when the elongation and reduction in area become nil. These experiments are of practical importance, since many steels carry an appreciable proportion of arsenic. Some chemists take little cognizance of this fact, and their phosphorus determinations are too high on account of the presence of arsenic in the phosphorus precipitate. Other analysts take special precautions to avoid this contamination.

SEC. XVIIi.—*Influence of nickel, tungsten and chromium.*—The first public presentation of the effect of nickel upon steel was a paper by Jas. Riley.† Since that time the properties of nickel steel have become widely known. As often happens in the case of a new metal, the tendency is to exaggerate its importance. In a paper read before the American Society of Civil Engineers, in June, 1895, I gave the detailed results found by testing nickel steel when rolled into rounds, angles and plates, and compared them with the records of carbon steel of the same tensile strength. A condensation of the work will be found in Table XVII-L. The nickel steel is superior, but in less measure than may be generally supposed. It must be kept in mind, however, that in armor plate, as in many another field, there is sometimes but a very small distance between absolute success and absolute failure, and that it matters little how much margin there is above success, provided there is a margin at all.

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* *The Effect of Arsenic on Steel. Journal I. and S. I.*, Vol. I, 1895, p. 77.
† *Alloys of Nickel and Steel. Journal I. and S. I.*, Vol. I, 1889, p. 45.

In 1903 a pamphlet was issued on nickel steel, by A. L. Colby. His conclusions may be thus summarized:

Three per cent. of nickel in steel of 0.25 per cent. carbon

TABLE XVII-L.

Nickel Steel as Compared with Carbon Steel.

NOTE.—All steels were made in an acid open-hearth furnace by The Pennsylvania Steel Company.

Kind of steel.	Composition; per cent.				
	C.	Mn.	P.	S.	Ni.
Nickel	.24	0.78	.062	.027	3.25
Hard forging	.30 to .35	.60 to 1.00	.08 to .05	.08 to .05	nil.
Forging	.25 to .30	.60 to .80	.08 to .06	.08 to .07	nil.

Shape of member.	Kind of steel.	Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elastic ratio; per cent.	Elongation in 8 inches; per cent.	Elongation in 2 inches; per cent.	Reduction of area; per cent.
Rounds,	Nickel	86015	63575	73.9	20.19	34.00	46.3
	Hard forging	87663	58055	66.2	16.70	24.44	30.3
	Forging	78066	51708	66.3	23.94	. . .	52.0
Angles,	Nickel	86960	58558	67.3	21.75	39.67	50.5
	Hard forging	87820	54158	61.7	19.25	34.33	43.3
	Forging	76970	49544	64.4	. . .	. . .	49.6
Universal plates, longitudinal,	Nickel	85773	58410	68.1	21.08	39.25	52.0
	Hard forging	82773	50163	60.6	20.50	37.67	47.0
	Forging	73996	46654	59.1	26.78	. . .	52.1
Universal plates, transverse,	Nickel	86417	56203	67.4	16.50	28.92	36.1
	Hard forging	85173	(50000)*	(58.7)*	18.33	23.17	27.4
	Forging	. . . . .	. . . . .	. . . . .	. . .	. . .	. . .
Sheared plates, longitudinal,	Nickel	85337	58169	68.2	19.00	35.50	48.3
	Hard forging	85012	(50000)*	(58.8)*	22.10	30.40	48.4
	Forging	78918	49128	62.3	22.08	. . .	50.8
Sheared plates, transverse,	Nickel	84377	57260	67.9	17.13	32.50	43.4
	Hard forging	84527	(50000)*	(59.3)*	21.71	27.00	41.3
	Forging	. . . . .	. . . . .	. . . . .	. . .	. . .	. . .

produces a metal as strong as simple carbon steel of 0.45 per cent. carbon, but with the ductility of the lower carbon steel.

On low-carbon steels not annealed, each 1 per cent. of nickel up to 5 per cent. causes an increase of 5000 pounds in the elastic limit and 4000 pounds in the ultimate strength, high-carbon steels showing more gain than soft steel, the higher elastic limit giving more working capacity.

* Approximate; could not determine accurately.

Nickel steel has the same modulus of elasticity as carbon steel; it has greater resistance to shock and torsional strains and to compression. This is not due to hardness, as it is readily cut by ordinary tools, and soft steel cannot be made hard merely by the addition of nickel.

Nickel steel has superior stiffness, but bends to greater angles before rupture; plates of this metal are not weakened by punching as much as those of carbon steel. In bridge construction the usual allowance for expansion can be made. The shearing strength is greater than with carbon steel. Nickel segregates only slightly even in the largest ingots.

There are other elements used to make special alloys with iron, some of these metals being of considerable importance. Tungsten and chromium are both employed to give tool steels extreme hardness, their characteristic being that no quenching or tempering is required. These alloys, however, do not come under the head of structural material, and will therefore not be considered here.

SEC. XVIIj.—*Influence of oxide of iron.*—The last step in the making of a heat of steel is the addition of the recarburizer to wash the oxygen from the bath, but this action is not perfect, and the exact relation is not generally understood. The amount of oxygen taken from the metal will be measured in a rough way by the amount of manganese and other metalloids that are burned during the reaction. This is particularly true of acid practice. In basic work there is oftentimes a very considerable loss of manganese through the presence of free oxygen in the slag. This occurs in the acid furnace, but less frequently. The loss of manganese in recarburization is a function of the quantity which is added. In other words, a reduction in the percentage of manganese added to an open-hearth bath at the time of tapping means a reduction in the amount of manganese oxidized, and this proves that the reaction is not perfect, and that an increasing amount of oxygen must remain in the metal as the content of manganese decreases; but a reasonable proportion of this oxygen can hardly exert any marked deleterious influence, else the fact would long ago have been known in some more definite form than the suppositions and theories which are occasionally founded on exceptional phenomena. Assuming that high oxygen will more likely be found in steels low in manganese, it may reasonably be expected that any bad effect will be

seen in the softest products of the basic open-hearth and in the purest of acid steel. On the contrary, it is well known that the reverse is true, and that the ductility increases as the condition of pure iron is approached.

TABLE XVII-M.

Data on Very Soft Basic Open-Hearth Steel.

Heat number.	Carbon by combustion; per cent.	Carbon by color; per cent.	Phosphorus; per cent.	Manganese; per cent.	Sulphur; per cent.	Copper; per cent.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elastic ratio; per cent.
4009	. . .	.04	.007	.02	.024	.10	28420	45620	62.8
4009	. . .	.04	.007	.05	.019	.05	30640	46310	66.2
4980	. . .	.04	.007	.04	.021	.06	24370	46000	53.0
4982	. . .	.04	.011	.04	.029	.04	25810	46480	55.5
4971	. . .	.08	.010	.05	.032	.14	26780	47140	56.8
4972	. . .	.04	.010	.04	.021	.10	27920	47000	59.4
Average,	.025	.04	.009	.04	.024	.08	27323	46425	58.9

In a discussion of a paper by Webster, H. D. Hibbard* deduced the fact that oxide of iron reduces the tensile strength of very soft metal by several thousand pounds. I cannot indorse this conclusion, but offer Table XVII-M as evidence to the contrary. These heats were made in a basic open-hearth furnace, and their regularity shows that we are dealing with a normal and definite metal and not with an accidental product. They were purposely made with the lowest possible content of manganese, and it seems certain that the steel must be saturated with oxygen. These steels are much stronger than would be expected as compared with those containing more carbon. It may be that the first increments of carbon have less strengthening effect than further additions, or it may be that the first increments of manganese have a marked weakening effect, but it is more probable that the oxide of iron increases the ultimate strength.

* *Trans. A. I. M. E.*, Vol. XXI, p. 999

PART II.

EFFECT OF CERTAIN ELEMENTS AS DETERMINED BY SPECIAL MATHEMATICAL INVESTIGATIONS.

SEC. XVIIk.—*Investigations by Webster.*—A comprehensive study of the physical formula of steel has been carried out by W. R. Webster.* He has used the laborious method of successive approximations, and by "cutting and trying" has found the effect of each element upon the ultimate strength, as well as the effect of the thickness and finishing temperature. The results are given by him as follows:

.01 per cent. of sulphur increases the tensile strength 500 pounds per square inch.

.01 per cent. of manganese has an effect which varies with each increment as follows, the values being expressed in pounds per square inch:

An increase in percentage	gives an increment of	making a total increase in strength over metal with no manganese of
from .00 to .15	3000	3000
" .15 to .20	1200	4200
" .20 to .25	1100	5300
" .25 to .30	1000	6300
" .30 to .35	900	7200
" .35 to .40	800	8000
" .40 to .45	700	8700
" .45 to .50	600	9300
" .50 to .55	500	10400
" .55 to .60	500	10900
" .60 to .65	500	11400

.01 per cent. of phosphorus has an effect which varies according to the amount of carbon present:

With .08 per cent. of carbon it is 800 pounds per square inch.
" .09 " " " " " " 900 " " " "
" .10 " " " " " " 1000 " " " "
" .11 " " " " " " 1100 " " " "
" .12 " " " " " " 1200 " " " "
" .13 " " " " " " 1300 " " " "
" .14 " " " " " " 1400 " " " "
" .15 " " " " " " 1500 " " " "
" .16 " " " " " " 1500 " " " "
" .17 " " " " " " 1500 " " " "

Carbon has a constant effect of 800 pounds for each .01 per cent.

SEC. XVIII.—*The value of carbon, manganese, phosphorus and iron in open-hearth steel as found by the method of least squares.*

* *Observations on the Relations between the Chemical Constitution and Physical Character of Steel. Trans. A. I. M. E.*, Vol. XXI, p. 766, and Vol. XXIII, p. 113; also *Journal I. and S. I.*, Vol. I, 1894, p. 328.

—Several years ago I made investigations by the method of least squares into the influence of the metalloids on open-hearth steel, and the former editions of this book contained details of the calculations. The following values were found:

.01 per cent.	Acid steel.	Basic steel.
	lb. per sq. in.	lb. per sq. in.
Carbon	1210	950
Phosphorus	890	1050
Manganese	....	85

The base was 38,600 pounds for pure iron for acid steel, and 37,430 pounds for basic metal. These formulæ have been used at the works of The Pennsylvania Steel Company for ten years, and it is unusual to have a difference of more than 2500 pounds per square inch between the calculated strength and the strength as actually found from the specimen rolled from a test ingot. The values have also been used commercially by other large steel works.

In making calculations by least squares, no assumptions are made and no preconceived theory can influence the work. The investigation resolves itself into the solution of certain mathematical equations, with only one possible answer. Notwithstanding this fact, the method has given unsatisfactory results in the hands of other investigators, probably because the number of observations was too limited and the errors too great. In the present case, the general correctness of the results proves that the method is applicable.

SEC. XVIIm.—*The value of carbon, manganese, phosphorus and iron in open-hearth steel as found by plotting.*—In a paper read before the New York meeting of the Iron and Steel Institute of Great Britain in October, 1904, I gave the details of an investigation of nearly seven hundred acid heats and eleven hundred basic heats of open-hearth steel. A complete analysis was made of each heat, the carbon being determined by combustion. The heats were combined into groups, one group being composed of heats showing carbon from 0.075 to 0.125 per cent.; another with carbon from 0.125 to 0.175 per cent.; and so on, making a division for each additional 0.05 per cent. of carbon. Table XVII-N gives the list of groups thus formed.

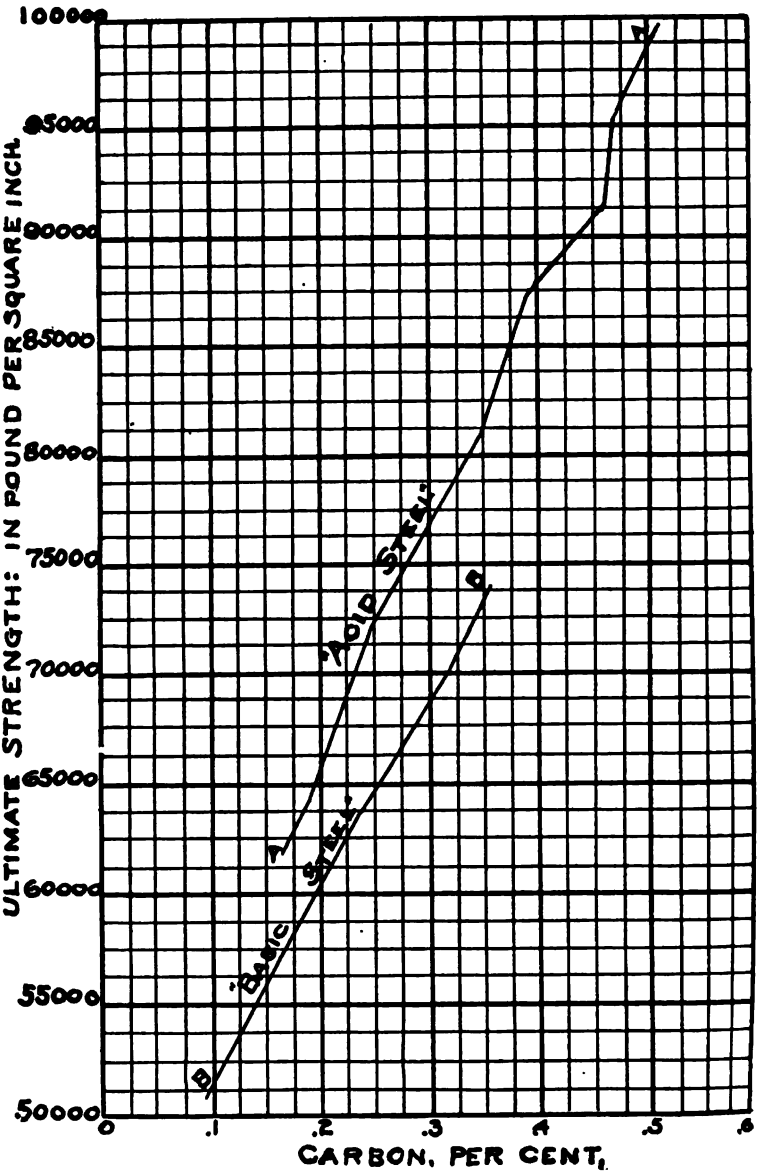


FIG. XVII-A.—STRENGTH OF STEEL FROM TABLE XVII-0.

The lines in Fig. XVII-A are not plotted from Table XVII-N, but the data have been combined to allow for the unequal number of heats in the groups. Thus by combining 1, 2 and 3 we get the first point of *AA;* from groups 2, 3 and 4 the second point; and so on. The result of this combination gives Table XVII-O, and the lines *AA, BB* take no account of variations in phosphorus or manganese. In the investigation by the method of least squares described in the preceding section it was found that 0.01 per cent. of phosphorus raised the strength of acid steel 890 pounds, and basic steel 1050 pounds per sq. in. In the present investigation the value of carbon is first determined, and then that of manganese and phosphorus, but in order to find the value of carbon accurately it is essential to know the influence of both manganese and phosphorus. This makes necessary the method of successive approximations, but in the present case the methods used avoid to some extent the dependence of one determination upon another. Thus in the line *AA,* carbon is the one great variable; the proportions of phosphorus and manganese are not constant, but the groups of high-carbon steel contain about the same amount of manganese and phosphorus as

TABLE XVII-N.

Groups Used to Find the Effect of Carbon, Phosphorus and Manganese.

Class.	Number of heats.	Carbon; per cent.	Phosphorus; per cent.	Manganese; per cent.	Ultimate strength; lbs. per square inch.
Line AA. Acid steel.	50	.1118	.0545	.408	58,012
	131	.1463	.0567	.437	61,039
	58	.1995	.0579	.475	66,809
	22	.2463	.0563	.484	70,736
	50	.3065	.0476	.528	79,058
	120	.3501	.0466	.537	83,093
	103	.4000	.0400	.518	87,156
	86	.4491	.0376	.520	92,824
	42	.4961	.0363	.519	98,224
	8	.5460	.0354	.495	102,346
	6	.5863	.0330	.498	107,398
Line BB. Basic steel.	135	.0451	.0092	.243	46,708
	125	.0974	.0084	.423	50,013
	134	.1521	.0116	.436	55,650
	246	.2044	.0113	.472	61,236
	263	.2484	.0110	.474	64,744
	125	.2935	.0106	.464	68,307
	27	.3413	.0113	.461	72,065
	11	.3932	.0120	.499	78,625
	1	.4310	.0070	.390	83,305

TABLE XVII-O.

Combination of Data in Table XVII-N to Obtain the Lines in Fig. XVII-A.

Class.	Carbon; per cent.	Phosphorus; per cent.	Manganese; per cent.	Ultimate strength; lbs. per sq. inch.
Line AA. Acid steel.	.1520	.0565	.440	61806
	.1713	.0570	.453	63697
	.2426	.0537	.497	72185
	.3268	.0480	.529	80626
	.3809	.0443	.528	83866
	.3943	.0419	.526	87155
	.4357	.0384	.519	91278
	.4696	.0371	.518	95052
	.5120	.0358	.513	99795
Line BB. Basic steel.	.0978	.0094	.396	50834
	.1639	.0107	.450	57001
	.2115	.0113	.465	61508
	.2403	.0110	.471	64066
	.2681	.0109	.470	66297
	.3061	.0108	.466	69626
	.3582	.0113	.469	74203

the groups of low-carbon steel, and hence the line will give a provisional value of carbon. The general trend is determined by stretching a thread along its length and noting the tangent made with the horizontal. In this way the line *AA* indicates a value for carbon of about 1050 pounds for each 0.01 per cent.; allowances have yet to be made for the effect of phosphorus and manganese, but this figure serves as a working basis for similar provisional estimations of the other elements. In explaining the method used to determine the value of phosphorus and manganese, no mention will be made of these provisional values, the figures given being in each case the final results.

THE EFFECT OF PHOSPHORUS ON ACID STEEL.

The study into the effect of phosphorus will be confined to acid steel, for in the basic steels under consideration the proportion of phosphorus was so low that the differences were almost within the limits of error. The bars were classified according to carbon and each of these main groups was then sub-divided according to phosphorus. Heats with 0.03 per cent. of phosphorus constituted one group; those with 0.031 per cent. another; those with 0.032 per cent. another, and so on. These groups were put together so as to give four or five points with an equal number of heats in each, the re-

sult being shown in Table XVII-P. In the last column is given what may be called the base, or the strength of the iron and phos-

FIG. 2.

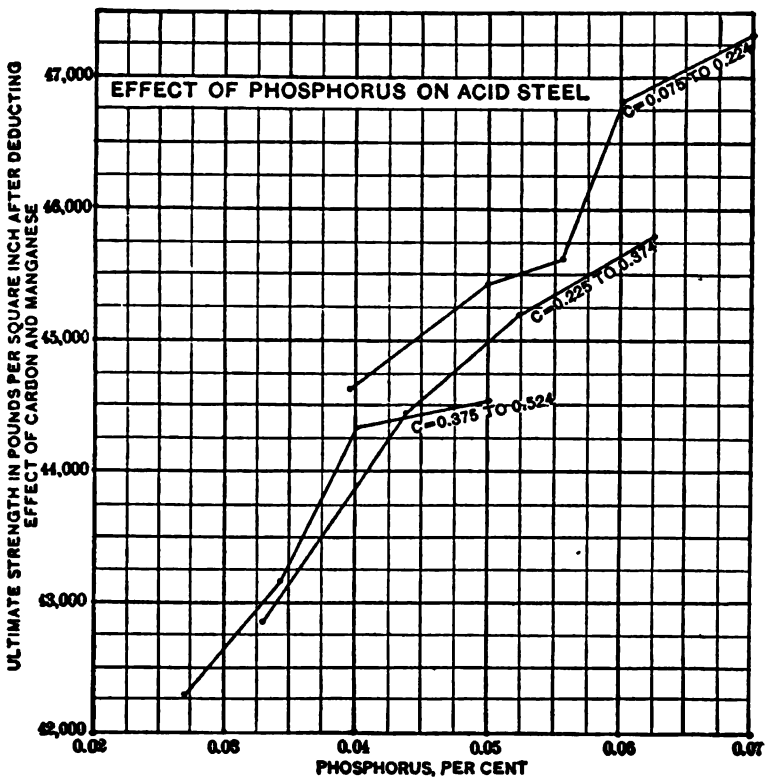


FIG. XVII-B.—EFFECT OF PHOSPHORUS ON ACID STEEL.

phorus after allowing for carbon and manganese; this last column is plotted in Fig. XVII-B. By combining the groups so as to rectify the lines by the method used in Table XVII-O, it will be found that, in the line representing heats ranging between 0.075 and 0.224 per cent. of carbon, the phosphorus has a value of about 860 lb. for each 0.01 per cent.; in the range from 0.225 to 0.374 per cent. of carbon, the value is 940 lb.; between 0.375 and 0.524 per cent. of carbon it is 1290 pounds. This would indicate that, as the percentage of carbon increases, the effect of each unit of phosphorus increases, but the difference is so unimportant and the margin of cer-

tainty so narrow that it will be better to make a true average of the three values. There were 239 heats giving a value of 860 lb., 192 heats giving 940 lb., and 231 heats giving 1290 lb., so that the true average is 1033 lb. For the sake of simplicity the value of 0.01 per cent. of phosphorus will be taken as 1000 pounds.

In reducing to a zero-base, as in the last column of Table XVII-P, there will be certain errors, since the values of carbon and manganese are not inerrant; but the original classification into groups of about the same carbon minimizes the disturbing effect. Thus in Table XVII-P the first main division has five units; the highest carbon is 0.1540 per cent. and the lowest 0.1491 per cent., a varia-

TABLE XVII-P.

Classification of Acid Heats According to Content of Phosphorus.

NOTE.—In the last column a value of 1,000 lbs. is given to 0.01 per cent. of carbon; the figure for manganese is taken from Table XVII-R. Fig. XVII-B is plotted from the last column, but the data are combined to rectify the lines.

Limits of carbon; per cent.	Number of heats.	Chemical composition.				Ultimate strength.	
		Carbon. per cent	Phosphorus; per cent.	Manganese; per cent.	Sulphur; per cent.	Actual records; pounds per sq. inch.	After deducting for carbon and manganese; pounds per sq. inch.
0.075 to 0.224	39	0.1491	0.0396	0.439	0.0539	59944	44616
	54	0.1524	0.0500	0.430	0.0559	61038	45438
	38	0.1504	0.0557	0.441	0.0568	61595	46063
	61	0.1528	0.0617	0.445	0.0588	62633	46613
	47	0.1540	0.0717	0.447	0.0623	63292	47328
0.225 to 0.374	46	0.3373	0.0331	0.514	0.0477	79636	42805
	53	0.3317	0.0428	0.537	0.0529	81231	44444
	44	0.3265	0.0523	0.527	0.0538	81197	45194
	49	0.3120	0.0626	0.537	0.0537	80990	45792
0.375 to 0.524	52	0.4413	0.0271	0.514	0.0437	90413	42270
	63	0.4424	0.0343	0.508	0.0461	91180	43138
	54	0.4366	0.0404	0.521	0.0494	92215	44320
	62	0.4235	0.0504	0.584	0.0526	91370	44517

tion of 0.0049 per cent. Carbon has been valued at 1000 lb. for 0.01 per cent., and if perchance that value is in error by 50 lb. the results determined from that division of the table will be wrong by only $50 \times 0.49 = 25$ lb. The last column shows a strength of 47,328 lb. for one base and 44,616 lb. for the other, a difference of 2712 lb., so that the assumed error of 50 lb. in the value of carbon produces an error of only 1 per cent. in the value of phosphorus in this particular division. This argument applies also

to the determination of the other elements in both acid and basic steel.

Another important consideration applying equally to the work on phosphorus and on manganese is the concordance of results obtained from different divisions. A general average obtained by grouping any data into two primal divisions gives conclusions of very limited value, but in this paper the practice is followed by subdividing in order to compare results. Thus from three independent lines of Fig. XVII-B the values of phosphorus varied from 860 to 1290. It is quite possible that these variations were not accidental and that the variation represents a law of increasing effect with higher carbons; but, leaving all this aside, it is certain that three separate determinations roughly agreeing with one another establish with reasonable certainty the general fact that 0.01 per cent. of phosphorus has a strengthening effect of somewhere about 1000 lb. The validity of the conclusions is much superior to one based on a general average.

EFFECT OF MANGANESE ON ACID STEEL.

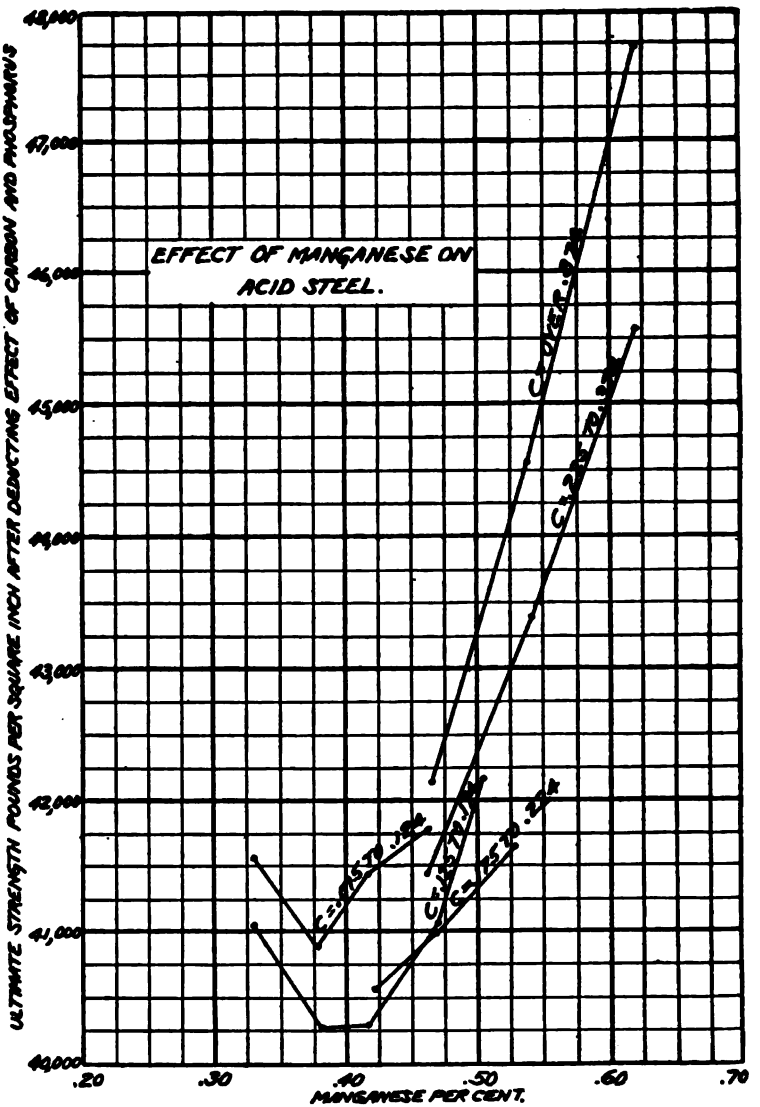
The heats were divided according to their content of manganese in the same way as in the determination of phosphorus. The results as given in Table XVII-Q and in Fig. XVII-C show that when the manganese exceeds 0.4 per cent. each increase in that element raises the strength, while with a content below 0.4 per cent. the tensile strength increases as the manganese decreases. The number of observations of low-manganese acid steels is not sufficient to prove this conclusively, but on another page it will be shown that in basic steel, also, a decrease in the manganese content below a certain point is not accompanied by a decrease in strength. It is probable that low manganese implies the presence of iron oxide and that this strengthens the steel much more than it is weakened by the decrease in manganese.

The lines in Fig. XVII-C show that each increase in manganese above 0.4 per cent. is accompanied by an increase in strength, but this increase is not the same with steels of different carbon. In steels containing more than 0.374 per cent. of carbon, each increase of 0.01 per cent. of manganese augments the tensile strength by about 440 lb. per sq. in. In Table XVII-Q it is shown that the average carbon of this group is about 0.44 per cent., and we thus

determine that, for a steel of 0.44 per cent. of carbon, the strengthening effect of 0.01 per cent. of manganese is about 440 lb. per sq. in.

FIG. XVII-C.

EFFECT OF MANGANESE ON ACID STEEL.



In the same way the line of next lower carbon shows that, in steels of 0.33 per cent. of carbon, the strengthening effect is about 260 lb. per sq. in. The next three lines may be considered as a unit indicating that, for steels of 0.155 per cent. of carbon, the strengthening effect is about 125 lb. per sq. in. Plotting these data it was found that the strengthening effect of each 0.01 per cent. of manganese above a content of 0.4 per cent. is 80 lb. per sq. in. for a steel of 0.1 per cent. of carbon, but that for each rise of 0.01 per

TABLE XVII-Q.

Classification of Acid Heats According to Content of Manganese.

NOTE.—In the last column both carbon and phosphorus are valued at 1,000 pounds for 0.01 per cent.

Limits of carbon; per cent.	Limits of manganese; per cent.	Number of heats.	Chemical composition; per cent.				Ultimate strength; pounds per sq. in.	
			Carbon.	Phosphorus.	Manganese.	Sulphur.	Actual records.	After deducting for carbon and phosphorus.
0.075 to 0.124	0.30 to 0.35	6	0.1052	0.0548	0.330	0.0560	57558	41558
	0.36 to 0.39	12	0.1117	0.0500	0.377	0.0576	57047	40877
	0.40 to 0.44	20	0.1110	0.0564	0.416	0.0589	58173	41433
	0.45 to 0.49	11	0.1168	0.0568	0.462	0.0596	59135	41775
0.125 to 0.174	0.30 to 0.35	2	0.1330	0.0585	0.330	0.0550	60900	41050
	0.36 to 0.39	19	0.1354	0.0538	0.381	0.0564	59189	40269
	0.40 to 0.44	55	0.1459	0.0569	0.417	0.0579	60560	40280
	0.45 to 0.49	41	0.1477	0.0564	0.470	0.0595	61493	41073
	0.50 to 0.59	14	0.1606	0.0601	0.508	.....	64258	42163
0.175 to 0.224	0.40 to 0.44	16	0.2004	0.0562	0.422	0.0504	66237	40577
	0.45 to 0.49	23	0.2016	0.0567	0.468	0.0567	67020	40990
	0.50 to 0.59	19	0.1980	0.0579	0.527	.....	67095	41645
0.225 to 0.374	0.40 to 0.49	47	0.3127	0.0476	0.461	.....	77471	41441
	0.50 to 0.59	122	0.3305	0.0482	0.541	.....	81257	43387
	0.60 to 0.69	19	0.3413	0.0476	0.618	.....	84463	45573
Over 0.374	0.40 to 0.49	33	0.4495	0.0359	0.465	.....	90680	42140
	0.50 to 0.59	144	0.4387	0.0395	0.537	.....	92365	44545
	0.60 to 0.69	17	0.4461	0.0387	0.618	.....	96218	47738

cent. of carbon the strengthening effect is increased 8 pounds. Thus an increase in manganese from 0.4 to 0.41 per cent. in steel of 0.1 per cent. of carbon raises the strength 80 lb., but an increase in manganese from 0.4 to 0.41 per cent. in steel of 0.11 per cent. of carbon raises the strength 88 pounds. A continuation of the line thus plotted gave zero-effect for zero carbon. With basic steel it

will appear that a different value was obtained for a starting point and a different value for the increment. The law of variation in the effect of manganese upon acid steels is shown in Table XVII-R.

It is possible to calculate manganese in the same way that phosphorus was determined, by making a true average of the different values of manganese found from the lines in Fig. XVII-C. After doing this and carrying out the system of successive approximations to the end, it was found that each .01 per cent. of manganese in acid steel in excess of .40 per cent. raised the strength 250 pounds per square inch. This change in the value of manganese made a slight change in the value of carbon and in the base, and when the new formula was applied to the list of groups, as in Table XVII-Y, it was found that it did not give as accurate results as the original formula with the sliding scale for manganese.

EFFECT OF SULPHUR ON ACID STEEL.

The heats were classified according to their sulphur content, the results being given in Table XVII-S and in Fig. XVII-D. It is shown that sulphur has little influence upon the strength of acid steel.

TABLE XVII-R.

Effect of Manganese upon Acid Steel.

Carbon; per cent.	Manganese; pounds per square inch.										
	Per cent. 0.40	Per cent. 0.42	Per cent. 0.44	Per cent. 0.46	Per cent. 0.48	Per cent. 0.50	Per cent. 0.52	Per cent. 0.54	Per cent. 0.56	Per cent. 0.58	Per cent. 0.60
0.10	.....	160	320	480	640	800	960	1120	1280	1440	1600
0.15	.....	240	480	720	960	1200	1440	1680	1920	2160	2400
0.20	.....	320	640	960	1280	1600	1920	2240	2560	2880	3200
0.25	.....	400	800	1200	1600	2000	2400	2800	3200	3600	4000
0.30	.....	480	960	1440	1920	2400	2880	3360	3840	4320	4800
0.35	.....	560	1120	1680	2240	2800	3360	3920	4480	5040	5600
0.40	.....	640	1280	1920	2560	3200	3840	4480	5120	5760	6400
0.45	.....	720	1440	2160	2880	3600	4320	5040	5760	6480	7200
0.50	.....	800	1600	2400	3200	4000	4800	5600	6400	7200	8000
0.55	.....	880	1760	2640	3520	4400	5280	6160	7040	7920	8800
0.60	.....	960	1920	2880	3840	4800	5760	6720	7680	8640	9600

EFFECT OF CARBON ON ACID STEEL.

Having found the effect of manganese and phosphorus it becomes possible to correct the original line so as to determine the value of carbon. Table XVII-S gives the corrected values, which are plotted

TABLE XVII-S.

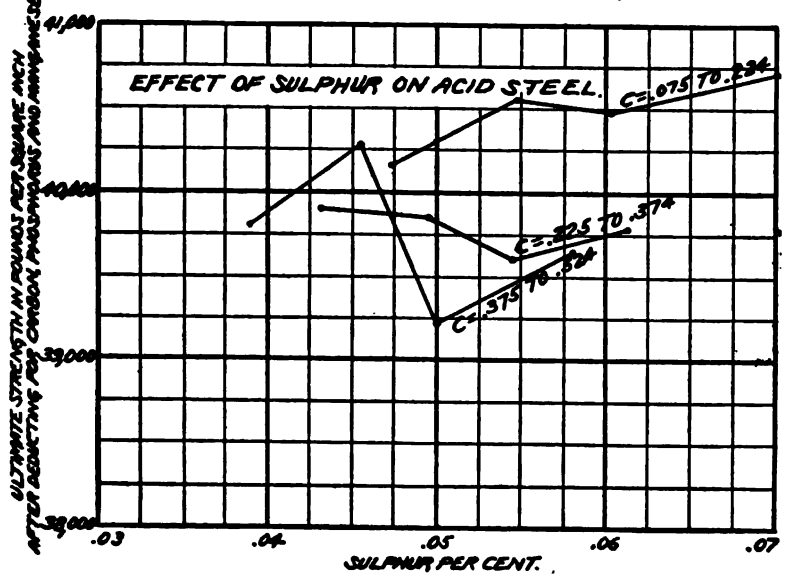
Classification of Acid Heats According to Content of Sulphur.

NOTE.--In the last column a value of 1000 pounds is given to 0.01 per cent. of both carbon and phosphorus; the figure for manganese is taken from Table XVII-R.

Limits of carbon; per cent.	Number of heats.	Chemical composition; per cent.				Ultimate strength; pounds per sq. in.	
		Carbon.	Phosphorus.	Manganese.	Sulphur.	Actual records.	After deducting for carbon, phosphorus, and manganese.
0.075 to 0.224	58	0.1601	0.0519	0.425	0.0474	61689	40169
	68	0.1457	0.0546	0.444	0.0547	61097	40561
	61	0.1551	0.0581	0.448	0.0602	62376	40486
	52	0.1474	0.0621	0.444	0.0706	62195	40717
0.225 to 0.374	44	0.3345	0.0401	0.518	0.0431	80478	39908
	37	0.3288	0.0470	0.527	0.0495	80798	39865
	60	0.3256	0.0499	0.533	0.0544	80670	39809
	51	0.3208	0.0532	0.535	0.0612	80582	39776
0.375 to 0.524	63	0.4356	0.0330	0.514	0.0389	90889	39916
	45	0.4419	0.0367	0.511	0.0454	92041	40274
	64	0.4378	0.0302	0.515	0.0500	90988	39240
	59	0.4290	0.0449	0.536	0.0579	91726	39658

FIG. XVII-D.

EFFECT OF SULPHUR ON ACID STEEL.



in Fig. XVII-G together with the final results on basic steel. The value of carbon for acid metal is shown by the tangent of the line with the horizontal, and is about 1000 pounds for each .01 per cent. The line intersects the zero ordinate at 40,000 pounds.

TABLE XVII-T.

Effect of Carbon upon Acid Steel.

NOTE.—In calculating the last column a value of 1000 pounds is given to 0.01 per cent. of phosphorus; manganese is rated according to Table XVII-R.

Class.	Chemical composition; per cent.			Ultimate strength; pounds per square inch.	
	Carbon.	Phosphorus.	Manganese.	Actual records.	After deducting for phosphorus and manganese.
Acid test-bars; carbon by combustion.	0.1580	0.0565	0.440	61806	55676
	0.1713	0.0570	0.453	63637	57216
	0.2486	0.0537	0.497	72185	64875
	0.3268	0.0480	0.529	80626	72472
	0.3609	0.0443	0.528	83886	75744
	0.3943	0.0419	0.526	87155	78996
	0.4357	0.0384	0.519	91278	83273
	0.4693	0.0371	0.518	95052	86917
	0.5130	0.0358	0.513	99795	91605

EFFECT OF MANGANESE ON BASIC STEEL.

The bars were classified according to their content of manganese as shown in Table XVII-U and in Fig. XVII-E. The line of very low-carbon and low-manganese steels shows that in the absence of manganese the strength is raised by iron oxide or by some other agent. In steels of higher carbon less oxygen is present, owing to the protecting power of carbon, and the decrease in strength with decrease in manganese holds good down to a content of 0.3 per cent. Considering only the lines representing steels with from 0.075 to 0.224 per cent. and with from 0.225 to 0.374 per cent. of carbon, and pursuing the same course of reasoning as explained in the valuation of manganese in acid steels, it appears that above the limit of 0.3 per cent. of manganese the effect of each unit of that element is greater in the steels of higher carbon. In the acid steel the value at zero carbon was zero, the effect of 0.01 per cent. of manganese in a steel of 0.1 per cent. of carbon was 80 lb., and this effect increased 8 lb. with each rise of 0.01 per cent. of carbon.

In basic steel the value of 0.01 per cent. of manganese at zero

TABLE XVII-U.

Classification of Basic Heats According to Content of Manganese.

NOTE.—In the last column a value of 770 pounds is given to 0.01 per cent. of carbon, and 1000 pounds to 0.01 per cent. of phosphorus.

Limits of carbon; per cent.	Limits of manganese; per cent.	Number of heats.	Chemical composition: per cent.			Ultimate strength; pounds per sq. inch.	
			Carbon.	Phosphorus.	Manganese.	Actual records.	After deducting for carbon and phosphorus.
Below 0.075	0.05 to 0.09	12	0.0297	0.0075	0.081	45803	42766
	0.10 to 0.14	56	0.0927	0.0073	0.120	45674	42426
	0.15 to 0.29	13	0.0888	0.0072	0.191	45961	42254
	0.30 to 0.39	16	0.0808	0.0097	0.354	48034	42360
	0.40 to 0.49	34	0.0632	0.0091	0.438	47981	42205
	0.50 to 0.59	4	0.0663	0.0133	0.508	51133	44698
0.075 to 0.224	0.20 to 0.29	7	0.1108	0.0079	0.259	50056	40773
	0.30 to 0.39	114	0.1458	0.0098	0.363	54110	41904
	0.40 to 0.49	242	0.1668	0.0099	0.441	57036	43203
	0.50 to 0.59	110	0.1744	0.0125	0.531	59316	44638
	0.60 to 0.69	26	0.1887	0.0154	0.622	61862	45793
0.225 to 0.374	0.30 to 0.39	61	0.2678	0.0089	0.365	63858	42349
	0.40 to 0.49	221	0.2689	0.0101	0.446	65949	44230
	0.50 to 0.59	102	0.2668	0.0130	0.532	67565	45723
	0.60 to 0.69	28	0.2695	0.0139	0.624	69467	47327

TABLE XVII-V.

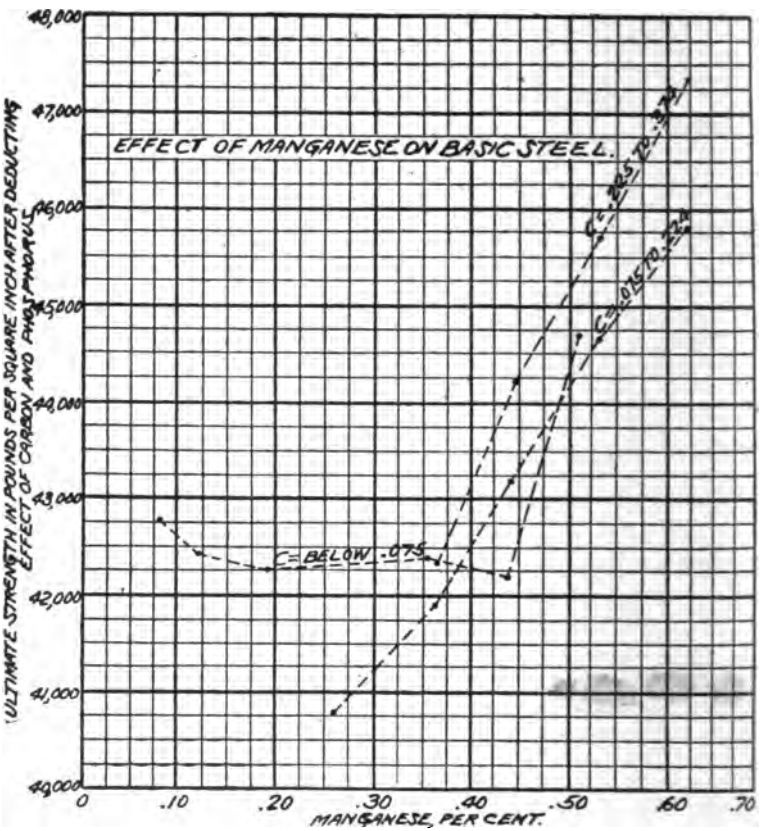
Effect of Manganese upon Basic Steel.

Carbon. per cent.	Manganese; pounds per sq. inch.						
	Per cent. 0.30	Per cent. 0.35	Per cent. 0.40	Per cent. 0.45	Per cent. 0.50	Per cent. 0.55	Per cent. 0.60
0.05	.....	550	1100	1650	2200	2750	3300
0.10	.....	650	1300	1950	2600	3250	3900
0.15	.....	750	1500	2250	3000	3750	4500
0.20	.....	850	1700	2550	3400	4250	5100
0.25	.....	950	1900	2850	3800	4750	5700
0.30	.....	1050	2100	3150	4200	5250	6300
0.35	.....	1150	2300	3450	4600	5750	6900
0.40	.....	1250	2500	3750	5000	6250	7500

carbon is 90 lb.; the effect per 0.01 per cent. of manganese at 0.1 per cent. of carbon is 130 lb., and the increase in effect due to a

rise of 0.01 per cent. of carbon is only 4 pounds. In the acid steel the base is 0.4 per cent. of manganese; in the basic steel it is 0.3 per cent. The results are tabulated in Table XVII-V.

FIG. XVII-E.
EFFECT OF MANGANESE ON BASIC STEEL.



As in the case of acid steel before explained, an attempt was made to get a uniform value for manganese. The figure found for basic steel was 160 pounds for each .01 per cent. over .30 per cent., but as with acid steel it was found that such a formula did not give as close agreement between the calculated and the actual ultimate strength as when the variable value of manganese was used.

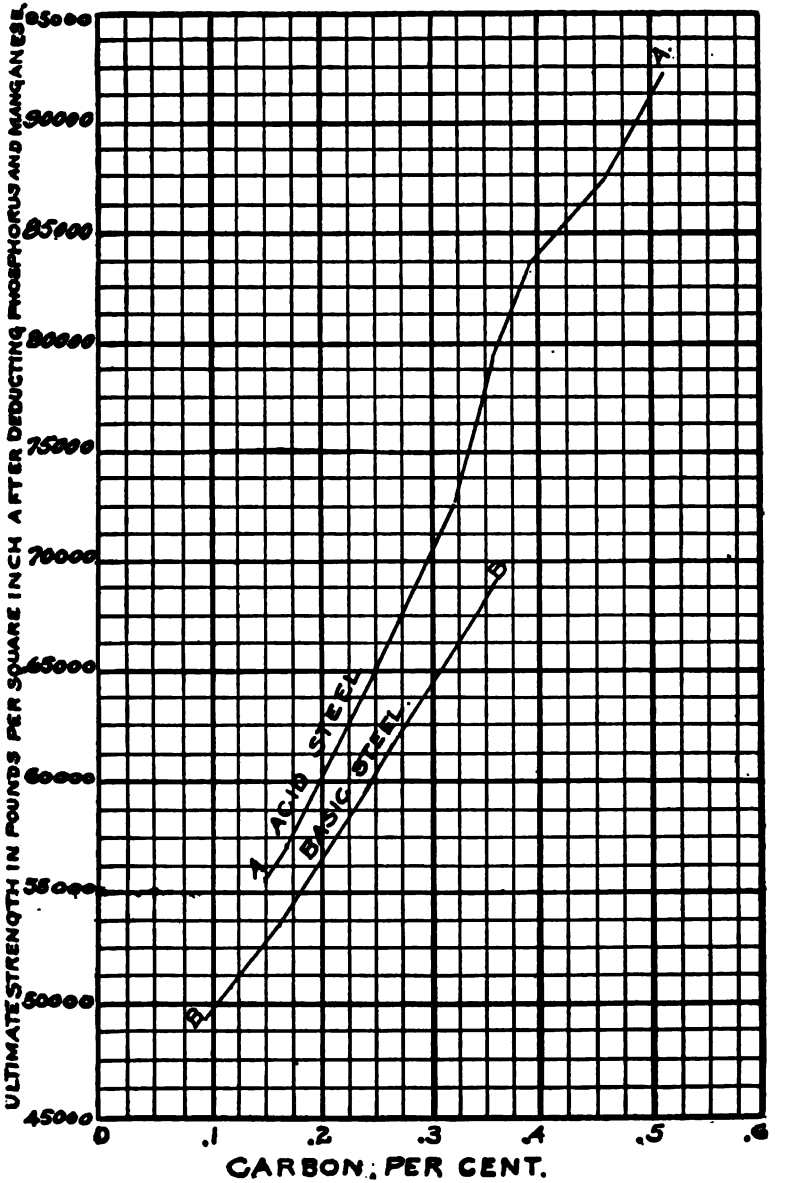


FIG. XVII-G.—EFFECT OF CARBON ON STEEL, FROM TABLES XVII-T AND XVII-X.

TABLE XVII-W.

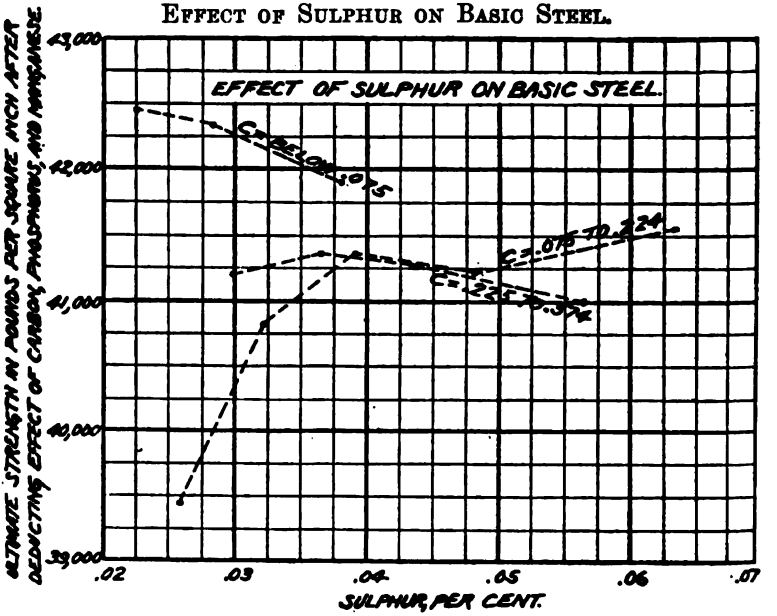
Classification of Basic Heats According to Content of Sulphur.

NOTE.—In the last column a value of 770 pounds is given to 0.01 per cent. of carbon, and 1000 pounds to 0.01 per cent. of phosphorus; manganese is rated as shown in Table XVII-V.

Limits of carbon; per cent.	Number of heats.	Chemical composition per cent.				Ultimate strength; pounds per sq. in.	
		Carbon.	Phosphorus.	Manganese.	Sulphur.	Actual records.	After deducting for carbon, phosphorus, and manganese.
Below 0.075	45	0.0361	0.0074	0.162	0.0225	45978	42458
	46	0.0418	0.0077	0.212	0.0283	46937	42348
	44	0.0575	0.0096	0.356	0.0380	47923	41806
0.075 to 0.224	74	0.1225	0.0078	0.434	0.0256	51584	39462
	103	0.1571	0.0089	0.444	0.0322	50027	40822
	112	0.1786	0.0114	0.466	0.0391	53944	41363
	105	0.1790	0.0115	0.461	0.0482	58767	41226
	110	0.1696	0.0129	0.441	0.0632	58129	41552
0.225 to 0.374	115	0.2754	0.0083	0.453	0.0296	66338	41206
	113	0.2693	0.0097	0.456	0.0365	66194	41360
	89	0.2679	0.0114	0.464	0.0434	66307	41298
	98	0.2582	0.0149	0.504	0.0563	66334	41005

FIG. XVII-F.

EFFECT OF SULPHUR ON BASIC STEEL.



EFFECT OF SULPHUR ON BASIC STEEL.

The heats were classified according to their sulphur content, as shown in Table XVII-W and in Fig. XVII-F. The lines are irregular and indeterminate, indicating a very small value for this element.

EFFECT OF CARBON UPON BASIC STEEL.

The effect of carbon was found, as in the case of acid steels, by allowing for phosphorus and manganese in the groups given in Table XVII-O. The data are given in Table XVII-X and in Fig. XVII-G. The line indicates a value of 770 lb. for each 0.01 per cent. of carbon and it intersects the zero ordinate at 41,500 pounds.

TABLE XVII-X.

Effect of Carbon upon Basic Steel.

NOTE.—In calculating the last column a value of 1000 pounds is given to 0.01 per cent. of phosphorus; the manganese is rated as shown in Table XVII-V.

Class.	Chemical composition; per cent.			Ultimate strength; pounds per square inch.	
	Carbon.	Phosphorus.	Manganese.	Actual records.	After deducting for phosphorus and manganese.
Basic test-bars; carbon by combustion.	0.0978	0.0094	0.366	50834	49086
	0.1639	0.0107	0.450	57001	53721
	0.2115	0.0113	0.465	61508	57501
	0.2403	0.0110	0.471	64086	59805
	0.2681	0.0109	0.470	66297	61841
	0.3081	0.0108	0.466	69626	64994
	0.3582	0.0113	0.469	74203	69118

It has already been explained that any change in the value of manganese affects the tangent of the carbon-line, thereby affecting the value found for a unit of that element; and as manganese has been given a slightly higher value in basic than in acid steel, it would naturally follow that the result for carbon would be lower in the basic than in the acid steel. To find how much this change in the value of manganese affected the carbon determination, the experiment was tried of correcting the line of basic, according to the values of manganese found for acid steel. The result showed a value of 810 lb. for 0.01 per cent. of carbon, instead of 770 lb. as found by the above special investigation. Inasmuch as the acid

steel gave a value for carbon of 1000 lb. per unit of 0.01 per cent., and as the basic steel gives 810 lb. when calculated by the acid formula and 770 lb. by its own formula, it would seem certain that a unit of carbon has much less effect upon basic than upon acid steel.

THE APPLICATION OF THE FORMULÆ.

Table XVII-Y shows the result of comparing the actual strength of the steels under consideration with the strength as calculated from the formulæ just given. For this purpose the heats were grouped according to carbon and then subdivided according to manganese. No heats were put together that varied more than 0.05 per cent. in carbon, or more than 0.1 per cent. in manganese. For instance, a group might include a heat containing 0.1 per cent. of carbon and 0.3 per cent. of manganese, and another heat containing 0.149 per cent. of carbon and 0.399 per cent. of manganese, but any heat of higher or lower carbon, or of higher or lower manganese than these extremes, would fall into another group. Inasmuch as the phosphorus did not vary through wide limits in any of the steels, each group may be looked upon as composed of heats that are practically alike in chemical composition, and which may properly be averaged to eliminate accidental errors.

In some of the subdivisions the number of heats is so small that these errors cloud the result. Especially in the steels of higher carbon it is desirable to have a large number of heats in the average, as it is difficult to get uniform results on a testing-machine under usual working conditions when the bar has a strength of over 90,000 lb. per sq. in., and unfortunately it is in these high steels, and particularly in the groups with an unusual content of manganese, that only a small number of heats were on record. There are, accordingly, several instances where these small groups show a considerable difference between the actual and the calculated strength, but there seems to be no rule as to the difference, as other groups, either large or small, of the same class of steels give satisfactory results.

It is, of course, a matter of opinion as to what constitutes a fair agreement between the actual and the calculated strengths, but in the following comparison it will be assumed that the results of the formulæ should be within 1500 lb. of the records of the testing-

machine. In the acid steels there are 12 groups containing less than 5 heats each. In 7 of these the calculated strength agrees with the actual strength within 1500 pounds. In 5 groups the difference

TABLE XVII-Y.

Comparison of the Actual Ultimate Strength of Certain Groups of Steel with the Strength as Calculated from the Following Formulæ:

Acid steel: $40000 + 1000\,C + 1000\,P + x\,Mn$ = ultimate strength.
Basic steel: $41500 + 770\,C + 1000\,P + y\,Mn$ = ultimate strength.

Value of x as per Table XVII-R; value of y as per Table XVII-V.
Italic type denote that the difference between the actual and calculated strengths is over 1500 pounds.

Limits of carbon; per cent.	Limits of manganese; per cent.	Number of heats.	Chemical composition; per cent.			Ultimate strength; pounds per square inch.		
			Carbon.	Phosphorus.	Manganese.	Actual records.	By formula.	Difference.
Acid steel:								
0.075 to 0.124	0.30 to 0.39	18	0.1095	0.0517	0.361	57217	56120	−1097
	0.40 to 0.49	31	0.1121	0.0566	0.432	58414	57258	−1156
	0.50 to 0.59	1	0.1130	0.0440	0.500	56745	56600	−145
0.125 to 0.174	0.30 to 0.39	21	0.1352	0.0542	0.377	59285	58940	−345
	0.40 to 0.49	96	0.1466	0.0567	0.440	60954	60794	−160
	0.50 to 0.59	14	0.1606	0.0601	0.513	64253	63536	−717
0.175 to 0.224	0.40 to 0.49	39	0.2011	0.0577	0.449	66698	66664	−34
	0.50 to 0.59	19	0.1960	0.0579	0.527	67035	67371	+336
0.225 to 0.274	0.30 to 0.39	1	0.2340	0.0550	0.390	68460	68900	+440
	0.40 to 0.49	11	0.2520	0.0576	0.468	71068	72200	+1132
	0.50 to 0.59	10	0.2413	0.0551	0.519	70602	71925	+1323
0.275 to 0.324	0.40 to 0.49	14	0.3098	0.0446	0.469	78200	77101	−1099
	0.50 to 0.59	32	0.3066	0.0485	0.541	79167	78950	−217
	0.60 to 0.69	*3*	*0.2883*	*0.0477*	*0.613*	*80223*	*78456*	*−1767*
	0.70 to 0.79	*1*	*0.3240*	*0.0500*	*0.720*	*84100*	*80320*	*+3220*
0.325 to 0.374	*0.30 to 0.39*	*1*	*0.3440*	*0.0340*	*0.300*	*81050*	*78700*	*−2350*
	0.40 to 0.49	22	0.3452	0.0446	0.455	80208	80496	+290
	0.50 to 0.59	80	0.3512	0.0472	0.544	83425	83873	+447
	0.60 to 0.69	16	0.3516	0.0472	0.619	86258	86012	+754
	0.70 to 0.79	1	0.3440	0.0450	0.700	86840	87180	+340
0.375 to 0.424	0.40 to 0.49	34	0.4009	0.0377	0.464	85205	85908	+703
	0.50 to 0.59	63	0.3996	0.0410	0.537	87880	88444	+564
	0.60 to 0.69	6	0.3993	0.0425	0.622	90596	91284	+686
0.425 to 0.474	0.40 to 0.49	27	0.4481	0.0363	0.462	90950	90672	−278
	0.50 to 0.59	53	0.4515	0.0382	0.539	93760	93974	+214
	0.60 to 0.69	6	0.4332	0.0378	0.617	93805	94587	+782
0.475 to 0.524	0.30 to 0.39	1	0.4770	0.0330	0.390	90775	91000	+225
	0.40 to 0.49	12	0.4955	0.0340	0.468	95745	95643	−102
	0.50 to 0.59	25	0.4961	0.0376	0.533	99699	99637	−62
	0.60 to 0.69	*4*	*0.5010*	*0.0365*	*0.617*	*104550*	*102430*	*−2120*
0.525 to 0.574	0.40 to 0.49	6	0.5463	0.0303	0.478	100718	101061	+343
	0.50 to 0.59	2	0.5490	0.0505	0.545	107230	106330	−900
0.575 to 0.624	0.40 to 0.49	4	0.5857	0.0312	0.462	105131	104904	−227
	0.50 to 0.59	*1*	*0.5770*	*0.0430*	*0.510*	*112700*	*107071*	*−5629*
	0.60 to 0.69	1	0.5850	0.0300	0.600	111100	110960	−240

Limit of carbon; per cent.	Limits of manganese; per cent.	Number of heats.	Chemical composition; per cent.			Ultimate strength; pounds per square inch.		
			Carbon.	Phosphorus.	Manganese.	Actual records.	By formula.	Difference.
Basic steel:								
0.020 to 0.074	0.00 to 0.09	12	0.0297	0.0075	0.081	45803	44537	−1266
	0.10 to 0.19	65	0.0386	0.0078	0.125	45645	44740	−905
	0.20 to 0.29	4	0.0543	0.0073	0.263	47094	46411	−683
	0.30 to 0.39	16	0.0808	0.0097	0.354	48084	47767	−317
	0.40 to 0.49	34	0.0838	0.0091	0.438	47981	48849	+868
	0.50 to 0.59	4	0.0863	0.0133	0.508	51133	50389	−744
0.075 to 0.124	*0.10 to 0.19*	*1*	*0.0990*	*0.0080*	*0.160*	*45780*	*46923*	*+1143*
	0.20 to 0.29	6	0.0993	0.0078	0.262	49378	49926	+548
	0.30 to 0.39	42	0.0963	0.0086	0.363	49963	50748	+1085
	0.40 to 0.49	*53*	*0.0955*	*0.0093*	*0.438*	*49607*	*51477*	*+1870*
	0.50 to 0.59	21	0.0998	0.0089	0.589	51900	53182	+1282
	0.60 to 0.69	2	0.0950	0.0085	0.660	55773	54345	−1428
0.125 to 0.174	0.10 to 0.19	1	0.1370	0.0070	0.160	52295	52749	+454
	0.30 to 0.39	41	0.1486	0.0107	0.359	54738	54897	+159
	0.40 to 0.49	64	0.1531	0.0114	0.445	55800	56596	+796
	0.50 to 0.59	24	0.1549	0.0130	0.535	57050	58300	+1250
	0.60 to 0.69	*3*	*0.1657*	*0.0213*	*0.640*	*59943*	*61693*	*+1750*
0.175 to 0.224	*0.20 to 0.29*	*1*	*0.1760*	*0.0080*	*0.240*	*54140*	*55872*	*+1732*
	0.30 to 0.39	31	0.2064	0.0104	0.367	59276	59611	+335
	0.40 to 0.49	125	0.2040	0.0098	0.441	60752	60670	−82
	0.50 to 0.59	65	0.2059	0.0135	0.527	62547	62698	+151
	0.60 to 0.69	21	0.2009	0.0152	0.616	62716	63987	+1271
	0.70 to 0.79	3	0.2050	0.0087	0.713	65507	65424	−83
0.225 to 0.274	0.20 to 0.29	1	0.2300	0.0070	0.260	61090	59909	−1181
	0.30 to 0.39	39	0.2456	0.0079	0.365	62185	62463	+278
	0.40 to 0.49	137	0.2489	0.0105	0.451	64425	64644	+219
	0.50 to 0.59	66	0.2490	0.0122	0.529	66107	66436	+329
	0.60 to 0.69	18	0.2495	0.0141	0.627	67048	68465	+1417
	0.70 to 0.79	*1*	*0.2740*	*0.0140*	*0.710*	*74970*	*72362*	*−2608*
	0.90 to 0.99	*1*	*0.2250*	*0.0150*	*0.940*	*67505*	*72305*	*+4800*
0.275 to 0.324	0.30 to 0.39	18	0.2986	0.0095	0.366	65921	66753	+832
	0.40 to 0.49	70	0.2967	0.0098	0.440	67888	68063	+175
	0.50 to 0.59	29	0.2907	0.0128	0.540	69725	70208	+477
	0.60 to 0.69	8	0.2900	0.0142	0.621	72402	71991	−411
0.325 to 0.374	0.30 to 0.39	4	0.3443	0.0200	0.355	70954	71286	+332
	0.40 to 0.49	14	0.3396	0.0096	0.437	71170	71660	+490
	0.50 to 0.59	7	0.3354	0.0114	0.524	72385	73572	+1207
	0.60 to 0.69	2	0.3675	0.0105	0.610	79515	78286	−1229
0.375 to 0.424	0.30 to 0.39	2	0.3830	0.0080	0.355	73620	73154	−466
	0.40 to 0.49	5	0.3836	0.0102	0.448	75107	76555	+1448
	0.50 to 0.59	*1*	*0.3800*	*0.0110*	*0.500*	*79750*	*77280*	*−2470*
	0.00 to 0.09	*2*	*0.4065*	*0.0220*	*0.645*	*85545*	*83832*	*−1713*
	0.70 to 0.79	*1*	*0.3920*	*0.0080*	*0.750*	*85200*	*83732*	*−1528*

is over 1500 pounds. In the basic steel there are 17 groups containing less than 5 heats and 9 of these agree within 1500 pounds. Eight groups show a difference greater than this amount. Taking both acid and basic steels, out of 29 "small" groups 16 are correct, and of the 13 that are beyond the limit 9 are single heats, most of them being steel of moderately high carbon.

In the acid steel there are 23 groups containing over 4 heats each, and all of them are within the limit of 1500 lb., only 5 having an

error exceeding 1000 pounds. In the basic steel there are 26 groups with over 4 heats, and 25 are within 1500 lb., and 17 within 1000 pounds. There is 1 group of 53 heats, averaging about 0.1 per cent. of carbon, which shows an error of + 1810 pounds. Putting aside mathematical errors which can hardly be present in this investigation (owing to repeated checking of the totals at each separate rearrangement), it may appear probable that this group contains some abnormal bars, and it may also appear possible that some of the other large groups show an agreement through the averaging of bars showing wide differences among themselves.

Table XVII-Z gives some information on this point. Every group in Table XVII-Y comprising more than 50 heats and containing less than 0.225 per cent. of carbon is subdivided so as to have only one-half the former variation in manganese. Thus, if a group comprised heats ranging from 0.4 to 0.49 per cent. of manganese, it is subdivided into one group ranging from 0.4 to 0.44 per cent., and another from 0.45 to 0.49 per cent. If the original group were an average of unlike units, it is probable that the fact would be made manifest by a wide difference between the two parts, but in no case is such a difference discernible.

In the case of the one group composed of 53 heats before mentioned, a more extended analysis is given in Table XVII-Z. It has been divided into 10 parts, the first containing only those heats that contained 0.4 per cent. of manganese, the second those with 0.41 per cent. of manganese, and so on. The number of heats in some of the subdivisions is small, and complete regularity could hardly be expected, but in these 10 subdivisions the smallest difference between the strength as calculated by the formula and the strength as found by the testing-machine is + 723 lb., and the greatest is +2729 lb., so that the deviation of this group from the general rule is not due to one or two abnormal bars. With this one exception, the cause of which remains unexplained, all the large groups show a difference of less than 1500 lb. between the actual and the calculated strength, which is perhaps as close an agreement as could be expected.

A careful analysis was made to discover whether anything could be learned from the so-called errors. If, for instance, the groups of low carbon had shown a considerable and uniform minus error and the groups of high carbon had uniformly shown a similar plus

TABLE XVII-Z.

Subdivision of the Groups in Table XVII-Y that contain over Fifty Heats, and are below 0.225 per cent. in carbon, with special subdivision of the one large group showing a difference of more than 1500 lb. between the actual and calculated strength.

Limits of carbon; per cent.	Limits of manganese; per cent.	Number of heats.	Chemical composition; per cent.			Ultimate strength; pounds per square inch.		
			Carbon.	Phosphorus.	Manganese.	Actual records.	By formula.	Difference.
Acid steel:								
0.125 to 0 174	0.40 to 0.44	55	0.1459	0.0569	0.417	60560	60484	−76
	0.45 to 0.49	41	0.1477	0.0564	0.470	61483	61250	−233
Basic steel:								
0.020 to 0.074	0.10 to 0.14	56	0.0827	0.0073	0.120	45674	44748	−926
	0.15 to 0.19	9	0.0819	0.0071	0.159	45458	44666	−792
0.075 to 0.124	0.40 to 0.44	33	0.0961	0.0086	0.418	49809	51294	+1485
	0.45 to 0.49	20	0.0946	0.0079	0.470	49434	51784	+2350
	0.40	12	0.0963	0.0075	0.400	48949	50965	+2016
	0.41	4	0.0888	0.0110	0.410	49510	50824	+1314
	0.42	5	0.0946	0.0080	0.420	49469	51096	+1627
	0.43	4	0.1012	0.0088	0.430	50626	51812	+1186
	0.44	8	0.0980	0.0091	0.440	51053	51776	+723
	0.45	4	0.0870	0.0078	0.450	48521	50869	+2348
	0.46	5	0.0922	0 0084	0.460	49893	51455	+1762
	0 47	3	0.0833	0.0078	0.470	48383	50718	+2335
	0.48	4	0.1135	0.0080	0.480	50993	53452	+2459
	0.49	4	0.0948	0.0075	0.490	49253	51982	+2729
0.125 to 0.174	0.40 to 0.44	32	0.1522	0.0114	0.418	55495	56129	+634
	0.45 to 0.49	32	0.1541	0.0114	0.473	56265	57102	+837
0.175 to 0.224	0.40 to 0.44	66	0.2036	0.0090	0.416	60344	60095	−249
	0.45 to 0.49	59	0.2046	0.0107	0.468	61208	61247	+39
	0.50 to 0.54	48	0.2063	0.0139	0.514	62358	62584	+226
	0.55 to 0.59	17	0.2049	0.0124	0.566	63086	63199	+113

error, then it would be probable that the value of carbon was too high and the base too low. Investigation failed to show any regular law either for groups of high and low carbon, or for groups of high and low manganese. The one fact which appears to be true of both acid and basic steel is that the steels that are low in carbon and low in manganese are stronger than would be called for by the formula, and it seems probable that this is due to iron oxide.

CONCLUSIONS.

Carbon.—In acid steel each 0.01 per cent. of carbon strengthens steel by 1000 lb. per square inch when the carbon is determined

by combustion. The strengthening effect is 1140 lb. for each 0.01 per cent. as determined by color, owing to the fact that the color-test does not determine all the carbon present.

In basic steel each 0.01 per cent. of carbon strengthens steel by 770 lb. per square inch when the carbon is determined by combustion. The strengthening effect is 820 lb. for each 0.01 per cent. as determined by color.

Phosphorus.—Each 0.01 per cent. of phosphorus strengthens steel by 1000 lb. per square inch.

Manganese.—Each 0.01 per cent. of manganese has a strengthening effect upon steel, and the effect is greater as the content of carbon increases. Below a certain content of manganese the effect is complicated by some disturbing condition, probably iron oxide, so that a decrease in manganese in very low-carbon steels is accompanied by an increase in strength. In acid steel each increase of 0.01 per cent. of manganese above 0.4 per cent. raises the strength of acid steel an amount varying from 80 lb. in a metal containing 0.1 per cent. of carbon to 400 lb. in a metal containing 0.4 per cent. of carbon. In basic steel each increase above 0.3 per cent. raises the strength an amount varying from 130 lb. in a metal containing 0.1 per cent. of carbon to 250 lb. in a metal containing 0.4 per cent. of carbon.

Sulphur.—The effect of sulphur on the strength of acid and of basic steel is very small.

Formulæ.—From the foregoing results, the following formulæ may be written, in which C=0.01 per cent. of carbon, P=0.01 per cent. of phosphorus, Mn=0.01 per cent. of manganese, R=a variable to allow for heat treatment, and the answer is the ultimate strength in pounds per square inch. The coefficient of manganese in acid steel, called x, is the value given in Table XVII-R, and applies only to contents above 0.4 per cent. The value of manganese in basic steel, called y, is the value given in Table XVII-V, and applies to contents above 0.3 per cent.

Formula for acid steel, carbon by combustion:

$$40{,}000+1000\,C+1000\,P+x\,Mn+R=\text{Ultimate Strength.}$$

Formula for basic steel, carbon by combustion:

$$41{,}500+770\,C+1000\,P+y\,Mn+R=\text{Ultimate Strength.}$$

CHAPTER XVIII.

CLASSIFICATION OF STRUCTURAL STEELS.

SECTION XVIIIa.—*Influence of the method of manufacture on the properties of steel.*—The first problem in writing specifications for structural steel is the advisability of prescribing the method by which it shall be manufactured. Some engineers hold that the way in which a bar or plate is made is a matter entirely beyond their dominion. Logically, this position is impregnable, but it is not so practically, for although there is no essential difference in the results obtained from open-hearth and Bessemer steel in the testing machine, there is good testimony to show that the product of the converter is an inferior metal. The evidence against Bessemer steel is made up of scattered individual opinions, many made on insufficient evidence, but they are too numerous to be ignored, and are fortified by the statements of men whose words are weighed, and who are disinterested in their decisions. Thus A. E. Hunt, with long experience as chief of The Pittsburg Testing Laboratory, wrote as follows:* "Numerous cases have come under our observation of angles and plates which broke off short in punching, but although makers of Bessemer steel claim that this is just as likely to occur in open-hearth metal, we have as yet never seen an instance of failure of this kind in open-hearth steel."

Mr. Hunt quotes (*loc. cit.*) from a paper by Wailes that "these mysterious failures occur in steel of one class, viz., soft steel made by the Bessemer process."

There is also the testimony of W. H. White, Director of Naval Construction, Royal Navy.† "With converter steel riveted samples have given less average strength, greater variations in strength, and

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* *The Inspection of Materials of Construction in the United States.* *Journal I. and S. I.* Vol. II, 1890, p. 316.

† *Experiments with Basic Steel.* *Journal I. and S. I.*, Vol. I, 1892, p. 35.

much more irregularity in modes of fracture than similar samples of open-hearth steel."

My own experience leads me to think that Bessemer steel requires more work for the attainment of a proper structure than open-hearth metal, so that a thick bar is more apt to have a coarse crystalline fracture. This may be ascribed to improper heat treatment, but if open-hearth metal would not be injured under a similar exposure, then there is a difference between the metals, and, if this be acknowledged, then there is no necessity for argument.

Bessemer metal has been used for rails, and these are exposed to great stress and shock, but a large number of rails break in service, and it is probable that the number of broken rails would be reduced if they were made of open-hearth steel. The making of open-hearth rails is a commercial question, and involves immense sums of money. Nearly all rails in America are made by the Bessemer process, and each rail-making plant must be regarded as a unit. The converting department is one factor of this unit, its whole scheme of operation being designed for the one purpose of supplying the blooming mill with just the right quantity of ingots. It may be that at a given rail-making works there is no open-hearth furnace plant at all. In such a case if open-hearth rails are wanted they can be made only by some such changes as the following:

(1) Bring cold blooms from other works, and erect a plant of heating furnaces.

(2) Bring cold ingots from other works, with the same necessity for heating furnace equipment. In both cases the extra fuel consumption and waste in heating would be serious matters.

(3) The foregoing propositions are temporary and the only true solution is an open-hearth plant. This calls for a large amount of capital, and when the plant gets into operation the Bessemer plant will become a scrap heap of no value whatever, for in order that it shall be of any value it must run, and in order that it may run, it would be necessary to build a complete plant of rolling mills to handle its product.

(4) Having written off the value of the Bessemer outfit as a dead loss, it is necessary to guarantee business to the open-hearth department in sufficient quantity to keep it in steady operation at a price in proportion to the increased cost. It is out of the question to operate the open-hearth plant on certain orders for open-hearth

rails at a slightly higher price, and then start up the Bessemer plant on other orders and let the open-hearth lie idle.

(5) It may seem possible to have a number of mills and have the open-hearth and Bessemer plants both operating continuously and distributing their product as orders demand. One or two works in the country are able to do this to a greater or less extent, but it is impossible to do it and maintain the proper coördination of dependent factors and keep the operating costs in each department at a minimum.

We may conclude, therefore, that small lots of open-hearth rails may be made, but their production on a large scale means a plant laid out with that end in view, and if this plant is not guaranteed a regular line of business extending over many years at an increased price, it will be a losing venture.

In the case of structural shapes there is no difficulty in obtaining all needed sections in open-hearth steel, and it should be used in all structures, like railroad bridges, where the metal is under constant shock. The method by which the steel is made cannot be discovered by ordinary chemical analysis. Certain experiments indicate that there is a difference between Bessemer and open-hearth steel in the character of the occluded gases, but it is doubtful if any expert would risk his reputation by asserting positively, from any such evidence, that a certain steel was made by either one or the other process.

SEC. XVIIIb.—*Chemical specifications.*—Another point concerning which there is room for discussion is the propriety of limiting the chemical composition. Some engineers contend that, if the physical tests are fulfilled, the making of the metal is an entirely foreign matter. This position is untenable, for it would be possible to make a steel with 0.25 per cent. of phosphorus which would satisfy the ordinary tests of strength and ductility, and although such a content could usually be detected in the shops, a considerable proportion of the bars might pass muster. It is impossible to fix a limit of phosphorus below which there is no danger of treacherous breakage, but it is certain that, as the content is reduced, the danger of disaster disappears. On this account it becomes the duty of the engineer to specify the composition of the metal that he buys.

In ordinary roof-trusses and similar work there is no necessity for stringency, and Bessemer steel with a maximum content of .10

per cent. of phosphorus may be allowed; but in railroad bridges, traveling cranes, and other structures where the steel is exposed to moving loads and continued shock, and where the consequence of failure may not be measured in money, the specifications should require the use of open-hearth steel. The phosphorus limit in acid steel should be .08 per cent. and in long span bridges it should be .06 per cent. In basic steel it should always be below .04 per cent.

It is necessary also to specify the manner in which the sample shall be taken for analysis. There are four methods of doing this, of which only one is correct, and this correct one is seldom or never used. Taking for illustration a rolled billet of steel three inches square, its cross-section may be mentally divided into nine equal squares, each having an area of one square inch. Eight of these squares are next to the surface, while one is in the interior. This central square will include the segregated portion of the mass. Ordinarily a sample of such a billet would be taken by drilling to a depth of half an inch, but this does not touch the interior core, and the chemical determinations will show too low a content of segregating metalloids.

Another method is to drill to the center, and take all the drillings that are made. Two-thirds of these drillings will come from the outside squares and one-third from the inside, or a ratio of two from the outside and one from the interior, while the true ratio is eight to one; hence the content of segregating metalloids found by this method is higher than the true average.

A third method is to take drillings from the central portion, but this will give a higher content of certain elements than will be found throughout the bar.

The fourth way is to plane the entire surface and get a true average, but this practice is seldom carried out.

In the case of angles, a fair sample can be obtained by drilling into the bar as far as the center, the results being only slightly higher than the true values. In plates it is more difficult to take a fair sample, since the segregated portion is in the body of the sheet, and it is usually impracticable to drill a hole without injuring the member. Great injustice may be done by unusual methods of sampling. It would be perfectly right to state in the contract that drillings were to be taken from the center of the plate, but it is not right to take them in this way in the absence of a previous

understanding. If the tests are made on the center portion the allowable maximum of phosphorus and sulphur should be raised 50 per cent.; e. g., from .04 to .06 or .06 to .09 per cent.

The elements other than phosphorus need not be rigidly limited, for some discretion should be left to the maker in the attainment of definite physical results. It is not uncommon to find specifications that give an upper limit for every element and require a tensile strength which cannot be obtained by the formula. The carbon should always be left open, so that if the maker wishes to reduce the phosphorus he may use carbon to get strength. Manganese may be limited to .60 per cent. on the steels under 64,000 pounds per square inch, and to .80 per cent. on harder metal. This will ensure a safe material, and not be a burden on the manufacturer. Silicon is of little importance, but the maximum may be placed at .04 per cent. for soft steel.

Sulphur concerns the manufacturer more than the engineer, for if too high the bar will crack in rolling and be imperfect, while it has no marked effect on the ductility of the finished piece. In eye-bars, however, there is danger that high sulphur may cause crystallization during the heating necessary to form the eye.

Copper may be entirely neglected, for no ill effect upon the cold properties of low steel has ever been traced to its action, while thousands of tons of excellent metal have been made with a content of .75 per cent.

Rivet steel, like eye-bar flats, stands on a different footing from other structural metal, for this must be heated and worked after leaving the place of manufacture. Only the best of material should be used, and it should be so soft that it will not be injured by cold working or crystallized by overheating. The phosphorus should not be over .04 per cent., the sulphur not over .05 per cent., and the tensile strength not over 60,000 pounds per square inch.

SEC. XVIIIc.—*Use of soft steel in structural work.*—It is not possible to arbitrarily state just what is the best tensile strength for every purpose, but in my opinion a softer metal should be used for bridges than is often employed, because, although a slight sacrifice is made in the ultimate strength, there is a gain in working strength due to higher elastic ratio, and a decided increase in toughness and resistance to shock, so that the calculations may be made on the same basis for the working load as with a harder metal. The fact

that the elastic ratio rises as the ultimate strength decreases is not generally recognized, but will be shown in Table XVIII-A. This compares the groups of angles in Table XIV-H, which are made by the same process, and are of the same thickness, and contain the same percentage of phosphorus. In every case the stronger steel gives a lower elastic ratio.

TABLE XVIII-A.

Rise in Elastic Ratio with Decrease in Ultimate Strength.

Kind of steel.	Content of phosphorus; per cent.	Thickness of angle, in inches.	Harder steels.			Softer steels.			Rise in elastic ratio in softer steels; per cent.
			Av. ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	Av. ultimate strength; pounds per square inch.	Average elastic limit; pounds per square inch.	Average elastic ratio; per cent.	
Basic O. H.	below .04	¼ to ⅜	58865	39692	67.43	52583	36284	69.07	1.64
		⅜ to ½	58588	37837	64.62	58171	34891	65.62	1.00
		½ to ¾	59235	37497	63.28	51908	34026	65.56	2.28
		¾ to 1	59125	36085	60.95	51923	32856	62.31	1.36
Acid O. H.	.05 to .07	¼ to ½	65656	43718	66.58	60845	40891	67.21	0.63
		⅝ to 1	65631	42191	64.28	60695	39415	64.94	0.66
Acid O. H.	.07 to .10	¼ to ½	66365	44496	67.03	60064	41148	68.50	1.47
		⅝ to 1	65777	42817	65.09	60583	40170	66.30	1.21
Acid Bess.	.07 to .10	¼ to ½	66277	46422	70.04	60659	42417	71.58	1.54
		⅝ to 1	65940	45280	68.66	59682	42518	71.00	2.34

The tendency in the first epoch of steel structures was toward a hard alloy, but later practice has been a continual progress toward toughness. There was a halt at a tensile strength of 60,000 pounds, not on account of any magic virtue in the figure, but because ordinary mild steels gave that result, and a higher price was charged for softer metal. Conditions today are different, for the introduction of the basic hearth has altered the economic situation. A steel of 50,000 to 58,000 pounds per square inch is a most attractive material, possessing all the good characteristics of wrought-iron with greater strength and toughness.

In many specifications the option is given between acid and basic open-hearth steel, but it costs more to make low-phosphorus metal by the acid than by the basic process, so that the terms of the specification should be enforced after the contract is awarded, out of justice to other bidders who have based their calculations on the

letter of the law. In steel above .08 per cent. of phosphorus, this difference in cost disappears.

SEC. XVIIId.—*Tests on plates.*—A spread of 10,000 pounds per square inch in the ultimate strength should be allowed on all sections, but it is especially necessary on plates. In trying to fill rigid specifications where no allowance is made for thickness, or where the allowable limits of strength are too narrow, the plate rollers have been driven to expedients which are dangerously near the line of deception. Thus, if it is required that a test be cut from one plate out of ten, the manufacturer will leave a coupon on every plate and test strips are cut from immediately next to them; after finding which plates fill the requirements, the coupons are cut from the others and the inspector is told that the pile is ready for him.

If every plate is to be tested, then a coupon is left upon each corner and a contiguous strip is privately tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be absurd to designate from which corner the test is to be taken. It is also certain that no one corner represents the center of the plate, for the edges are finished colder than the center, and in a plate rolled direct from an ingot the corners in no way represent the part which corresponds to the segregated portion of the ingot.

It is by care in the preliminary testing rather than by improvement in the quality of material that advances have been made. The mill managers have been aided by the inspectors, for most of these men are anxious to pass material which they know to be good. They allow the manufacturer to put part of a heat into thick plates and part into thin, and make the tests on three-eighths or one-half inch gauge; they pass over the sheets that are 100 inches wide, and cut the coupons from plates that are less than 70 inches. On the other hand, higher tests should be called for on plates under 42 inches wide. This is because they can be made on a universal mill, and since better results can be had in this way, it is right to demand what there is a simple way of obtaining. No allowance need be made for a variation in tensile strength for different shapes, but concessions should be made for differences in thickness. This arises from the fact that it is generally known beforehand whether a cer-

tain heat is to be rolled into angles, or plates, or eye-bars, and it is seldom necessary to put part of a heat into one shape and part into another. On the other hand, it is almost always necessary to roll a charge into more than one thickness and more than one size of angles, plates, etc., and it is an onerous restriction if proper allowance be not made for the variations due to different thickness.

SEC. XVIIIe.—*Standard size of test-pieces.*—In all the tensile tests a length of eight inches should be taken as the standard for all sections. For several years there have been conferences held in foreign lands to establish uniform methods of testing, and it has been officially recommended that in the case of rounds the length of the test-piece shall be proportional to the square root of the sectional area, the formula being given as follows: $l=12.0\sqrt{f}$ when l=the length in inches and f=the sectional area in square inches. In Table XVIII-B I have calculated from this formula the proper length for rounds from one-half inch to 1¼ inches in diameter. The length is greatly reduced as the diameter grows less, and this is equivalent to demanding less elongation, while on larger sizes the length is increased, this being the same thing as demanding more elongation.

It is difficult to compare this system, in which the elongation is constant and the length varies, with the system wherein the length is constant and the required elongation varies; but an attempt is made to do this by obtaining the proportional elongation for the different lengths from Curve *AA* in Fig. XVI-A, the results being given in the last column of the table. A long time has been spent in arriving at the standard length of eight inches, and it would be very unfortunate if a complicated substitute were introduced. Such a change, however, is unlikely from present indications.

It is understood throughout this book that the elastic limit is determined by the drop of the beam. I have no sympathy with that group of agitators who are trying to introduce new meanings to old terms, and to apply old terms to new factors. It matters not whether the drop of the beam does or does not mark the spot where the elongation ceases to be exactly proportionate to the load. It represents a critical point of failure, and this is acknowledged by the agitators before mentioned, who recommend its determination on all test-pieces.

Moreover, it is shown in Section XVIm that this is a definite

point which can be determined more accurately than the reduction of area, and nearly as accurately as the elongation. If a new point is desired, such as shown by an autographic device, then this new

TABLE XVIII-B.

Calculation of $12.0 \sqrt{f}$ for Different Diameters.

Diameter, in inches.	f, or area in square inches.	$\sqrt{f}$	$12.0 \sqrt{f}$ = length in inches of test-piece.	Per cent. of elongation for lengths in preceding column; from Curve A A, Fig. XVI-A
½	.1963	.443	5.32	33.2
5/8	.3067	.554	6.65	31.5
¾	.4417	.665	7.98	30.2
7/8	.6013	.775	9.30	29.3
1	.7854	.886	10.63	28.7
1⅛	.9940	.997	11.96	27.8
1¼	1.2271	1.108	13.30	27.1

point should be given a new name. The term "elastic limit" has been preëmpted, by general use, as part of a system of trade nomenclature to designate the point where the beam drops.

Upon this determination all specifications and contracts are based, and any attempt to ascertain the elastic limit in any other way is a change in the contract requirements which would not be sustained in a court of equity. All calculations upon factors of safety in existing bridges are based upon this "drop of the beam," and there seems to be no good reason why one arbitrary point should be substituted for another and no reason why future work should not be carried on under the present established and well-understood system.

SEC. XVIIIf.—*The quench-test.*—In regard to what is known as the quench-test, I am of the opinion that it is an absurdity when applied to ordinary structural material. It was defended by Mr. Hunt* on the ground that it would guard against careless heating and cooling in the mill or shops, but this suggests the query why such carelessness should be tolerated. It is assumed that the work is done by mills and shops that understand their business, and the steel should be made to fit the work in hand and not the ignorance of middlemen. It is right to make severe tests on the cold proper-

* *The Inspection of Materials of Construction in the United States. Journal I. and S. I.*, Vol. II, 1890, p. 312.

ties, for the derailment of a train will subject certain members to great deformation; such an accident is a possibility which human foresight seems powerless to avoid, but carelessness in the shop stands on a different footing, for it is caused by positive and unnecessary acts in error.

The quench-test depends upon slight differences in the methods of heating and cooling, differences almost imperceptible and unexplainable, and the same steel may be made to pass or fail under modes of treatment which seem inherently identical. It would appear, therefore, that no warrant exists for the imposition of this test upon material for a railroad bridge, which is not calculated to withstand a conflagration followed by a flood. This position is being taken by a large number of engineers, and a quench-test is rapidly becoming a thing of the past.

SEC. XVIIIg.—*Standard specifications.*—The first successful effort in America to standardize specifications for iron and steel was made in August, 1895, by the Association of American Steel Manufacturers. The formation of the American Section of the International Association for Testing Materials on June 16, 1898, was the next important move in this direction, but the work of both organizations has been superseded by the formation of The American Society for Testing Materials. This is an offshoot of the International Society, and its creation was made advisable by two conditions:

(1) The American members deem of first importance the construction of a uniform set of specifications for the use of buyer and seller, while the foreign members wish to discuss the refinements in methods of testing, postponing to the future the construction of a set of specifications.

(2) The results thus far obtained in America toward making working specifications render it very desirable that the work be pursued under some definite organization, representing engineers, manufacturers, inspectors and investigators.

The society was definitely organized at Atlantic City on June 12, 1902, and elected as its secretary, Prof. Edgar Marburg, of the University of Pennsylvania, Philadelphia, Pa. It publishes for general circulation its standard specifications on steel, and is trying to harmonize by open discussion at its meetings the conflicting views held by different engineering societies and committees.

CHAPTER XIX.

WELDING.

SECTION XIXa.—*Influence of structure on the welding properties.*—Wrought-iron may be welded so that the union is as strong as the rest of the bar, for by upsetting the piece there can be extra work put upon the metal, and since the strength of the original bar was dependent upon a great number of welds, the additional local heating and hammering may give a superior strength. Unfortunately, failure almost always takes place near the weld under destructive tests. A rod may break a short distance from the actual union, but this by no means shows perfect workmanship, for it arises from the overheating of the iron, without subsequent work to develop a proper structure.

In steel the conditions are different, for the bar is not a collection of fibers and welds, so that it is impossible to make any improvement in a properly worked piece by cutting it in halves and putting it together again. It is conceivable that a bar may be underworked or overheated, and that additional work can enhance the strength at the point of welding, but this assumption of a bad material to start with may be neglected. It is also possible to finish the hammering on a welded piece at a low temperature and thereby exalt the ultimate strength, but this will give a less ductile material.

It is also possible to have the weld stronger than the adjacent parts of the bar, for steel will be crystallized by high heat more readily than wrought-iron, and hence it can happen that the metal in the neighborhood of the weld has a bad structure due to lack of hammering after high heating. The higher the critical temperature necessary to produce crystallization, the less the danger from this source, so that freedom from phosphorus and sulphur is a matter of importance.

The difference in crystallizing power between wrought-iron and steel makes a comparison of the two impossible, but it may be

profitable to quote from Holley the following conclusions concerning iron:*

"(1) None of the ingredients except carbon in the proportions present seems to very notably affect the welding by ordinary methods. [The maximum percentages were P, .317; Si, .321; Mn, .097; S, .015; Cu, .43; Ni, .34; Co, .11; Slag, 2.262.]

"(2) The welding power by ordinary methods is varied as much by the amount of reduction in rolling as by the ordinary differences in composition.

"(3) The ordinary practice of welding is capable of radical improvement, the most promising field being in the direction of welding in a non-oxidizing atmosphere."

SEC. XIXb.—*Tensile tests on welded bars.*—The allowable contents of metalloids given in the foregoing synopsis will show the gulf that separates iron from steel, and this will be further indicated by Table XIX-A, which gives tests on welded steel bars of different compositions, the investigation having been conducted under my own direction. The lack of certainty and regularity is evident, and yet the smiths were men of long experience in handling steel, and fully understood that individual results were to be compared. The bars were of a size most easily heated and quickly handled, but the record is extremely unsatisfactory.

In the rounds, each workman has at least one bad weld against him, while there is only one heat which gave uniformly good results. Picking out the worst individual weld of each workman, blacksmith "*A*" obtained only 70 per cent. of the value of the original bar, "*B*" 54 per cent., "*C*" 58 per cent., and "*D*" only 44 per cent. The forging steel showed one weld with only 48 per cent., the common soft steel 44 per cent., while even the pure basic steel gave one test as low as 59 per cent. In some cases where the break took place away from the weld, the elongation was nearly up to the standard, this being true of the four tests of the seventh group, and it should be noted that this metal contained .35 per cent. of copper, but in the other pieces the stretch was low and the fracture so silvery that it was plain the structure of the bar had been ruined. In most cases where the test-bar broke in the weld, the pieces parted at the surfaces of contact, showing that no true union had taken

* *The Strength of Wrought-Iron as Affected by its Composition and by its Reduction in Rolling. Trans. A. I. M. E.*, Vol. VI, p. 101.

place; one or two fractures were homogeneous, but they showed the coarse crystallization that follows overheating.

The lap welds represent the method used in making pipe, and are a better criterion of the welding quality of the steel than the round pieces, for in making the union the pieces were simply laid together with no upsetting. All of this steel, both Bessemer and open-hearth, had been pronounced suitable for pipe, although it

TABLE XIX-A.

Tensile Tests on Welded Bars of Steel and Wrought-Iron.

Figures in parentheses indicate that the bar broke in the weld. N=natural bar; W=welded bar. * denotes that elongation is measured in 2 inches.

Kind of steel.	Conditions of test.	Composition; per cent.					N=natural. W=welded.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Name of smith.
		C.	Mn.	P.	S.	Cu.						
Acid O. H. forging	¾-inch round; lap weld.	.20	.89	.089	.03	.35	N	46670	70450	26.25	53.50	. . .
		. .	. . .	. . .	. . .	. . .	W	45890	(60940)	*10.00	19.78	A
		. .	. . .	. . .	. . .	. . .	W	45590	(55090)	*9.00	7.55	B
		. .	. . .	. . .	. . .	. . .	W	. . .	(40840)	*7.00	8.12	C
		. .	. . .	. . .	. . .	. . .	W	. . .	(42190)	*8.00	4.04	D
Acid Bess. forging	¾-inch round; lap weld.	.25	1.26	.083	.05	.35	N	56140	86000	22.25	35.40	. . .
		. .	. . .	. . .	. .	. . .	W	56750	(68810)	*4.00	29.39	A
		. .	. . .	. . .	. . .	. . .	W	. . .	(55020)	*6.00	0.75	B
		. .	. . .	. . .	. . .	. . .	W	. . .	(62060)	*5.00	6.50	C
		. .	. . .	. . .	. . .	. . .	W	. . .	(41980)	*2.00	2.10	D
Acid O. H. soft.	¾-inch round; lap weld.	.09	.46	.08	. . .	.35	N	40080	60680	30.00	58.20	. . .
		. .	. . .	. . .	. . .	. . .	W	38230	61060	*66.33	56.51	A
		. .	. . .	. . .	. . .	. . .	W	44080	60880	*36.00	58.50	B
		. .	. . .	. . .	. . .	. . .	W	45080	65610	. . . .	56.36	C
		. .	. . .	. . .	. . .	. . .	W	. . .	(36640)	*12.00	4.58	D
Acid O. H. soft.	¾-inch round; lap weld.	.09	.39	.076	. . .	.35	N	38940	56900	28.75	59.89	. . .
		. .	. . .	. . .	. . .	. . .	W	37550	57650	*39.00	62.18	A
		. .	. . .	. . .	. . .	. . .	W	37400	(42740)	*9.00	13.48	B
		. .	. . .	. . .	. . .	. . .	W	40910	(43910)	*10.50	14.55	C
		. .	. . .	. . .	. . .	. . .	W	39220	56790	*34.00	62.39	D
Acid O. H. soft.	¾-inch round; lap weld.	.09	.40	.08	. . .	.35	N	41670	56300	30.00	62.56	. . .
		. .	. . .	. . .	. . .	. . .	W	38740	(39490)	*6.00	8.68	A
		. .	. . .	. . .	. . .	. . .	W	. . .	(39550)	*7.00	10.79	B
		. .	. . .	. . .	. . .	. . .	W	38800	58880	*37.00	65.46	C
		. .	. . .	. . .	. . .	. . .	W	34460	50030	*16.00	23.22	D
Basic O. H. soft.	¾-inch round; lap weld.	.06	.55	.019	. . .	.35	N	33880	51760	32.75	65.35	. . .
		. .	. . .	. . .	. . .	. . .	W	37660	59650	*32.00	59.55	A
		. .	. . .	. . .	. . .	. . .	W	. . .	(39640)	*8.00	13.88	B
		. .	. . .	. . .	. . .	. . .	W	35870	(51850)	*27.00	46.77	C
		. .	. . .	. . .	. . .	. . .	W	31830	49690	*41.00	67.85	D
Basic O. H. soft.	¾-inch round; lap weld.	.06	.50	.014	. . .	.35	N	32580	48990	31.75	71.56	. . .
		. .	. . .	. . .	. . .	. . .	W	41980	54530	*26.00	66.68	A
		. .	. . .	. . .	. . .	. . .	W	35470	52100	*30.00	70.81	B
		. .	. . .	. . .	. . .	. . .	W	33380	54900	. . . .	72.81	C
		. .	. . .	. . .	. . .	. . .	W	30720	55110	*41.00	70.61	D

will be a revelation to most metallurgists that such a high content of copper could be allowed. All the bars broke across the weld with a more or less crystalline fracture, there being no instance where the separation was at the plane of union, so that, while thorough welding was proven, it was evident from the lessened ductility that the metal was overheated during the operation.

TABLE XIX-A.—Continued.

Kind of steel.	Conditions of test.	Composition; per cent.					N=natural. W=welded.	Elastic limit; pounds per square inch.	Ultimate strength; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Name of smith.
		C.	Mn.	P.	S.	Cu.						
Basic O. H. soft.	¾-inch round; lap weld.	.08	.50	.027	. . .	.85	N	39820	62000	30.00	55.96	. . .
		. .	. . .	. . .	. . .	. . .	W	37330	(49210)	*9.00	8.22	A
		. .	. . .	. . .	. . .	. . .	W	40880	59460	*30.00	48.15	B
		. .	. . .	. . .	. . .	. . .	W	44510	66380	. . .	48.54	C
		. .	. . .	. . .	. . .	. . .	W	. . .	(55560)	*17.00	. . .	D
Acid Bess. soft.	2x⅝-inch flats; lap weld.	.06	.36	.082	.054	.09	N	40780	59140	29.50	47.65	. . .
		. .	. . .	. . .	. . .	. . .	W	42780	50560	7.50	21.60	. . .
		.06	.40	.082	.054	.09	N	42020	61870	25.00	46.89	. . .
		. .	. . .	. . .	. . .	. . .	W	45150	55780	8.50	24.78	. . .
		.06	.45	.082	.054	.09	N	40740	60730	26.25	46.72	. . .
		. .	. . .	. . .	. . .	. . .	W	46720	58540	5.00	19.48	. . .
		.06	.35	.082	.054	.09	N	42680	60780	28.75	47.23	. . .
		. .	. . .	. . .	. . .	. . .	W	43850	48740	1.25	20.20	. . .
Basic O. H. soft.	2x⅝-inch flats; scarf weld.	.08	.17	.008	.016	.10	N	30800	45070	39.00	69.70	. . .
		. .	. . .	. . .	. . .	. . .	W	31690	48290	11.25	42.16	. . .
		.11	.32	.011	.029	.08	N	33600	50190	38.75	58.48	. . .
		. .	. . .	. . .	. . .	. . .	W	. . .	45900	8.50	34.11	. . .
		.11	.32	.006	.018	.11	N	35780	49580	33.00	56.92	. . .
		. .	. . .	. . .	. . .	. . .	W	32120	45280	10.00	22.18	. . .
		.09	.29	.005	.021	.10	N	30300	50050	33.00	59.82	. . .
		. .	. . .	. . .	. . .	. . .	W	37400	45280	7.50	41.08	. . .
Basic O. H. soft.	2x⅝-inch flats; lap weld.	.12	.36	.005	.022	.08	N	34580	51080	28.50	48.63	. . .
		. .	. . .	. . .	. . .	. . .	W	30840	41600	7.50	26.34	. . .
		.18	.39	.005	.025	.10	N	35470	50770	33.75	51.50	. . .
		. .	. . .	. . .	. . .	. . .	W	. . .	37000	7.50	29.88	. . .
		.12	.29	.005	.016	.10	N	30880	51300	31.25	52.62	. . .
		. .	. . .	. . .	. . .	. . .	W	33300	43530	7.00	29.31	. . .
		.12	.51	.005	.021	.09	N	37650	54770	26.25	41.94	. . .
		. .	. . .	. . .	. . .	. . .	W	35200	48280	7.00	21.74	. . .
Wrought-iron.	2x⅝-inch flats; lap weld.	. .	. . .	. . .	. . .	. . .	N	33890	50080	28.50	37.26	. . .
		. .	. . .	. . .	. . .	. . .	W	32950	39830	6.00	15.52	. . .
		. .	. . .	. . .	. . .	. . .	W	34060	40630	6.25	22.26	. . .
		. .	. . .	. . .	. . .	. . .	W	32700	45140	11.75	20.98	. . .
		. .	. . .	. . .	. . .	. . .	W	32040	44730	11.00	19.25	. . .
		. .	. . .	. . .	. . .	. . .	W	32760	38490	4.00	9.26	. . .

The figures on the iron bars show that the situation is no better than with steel, for the welded bars are far inferior to the natural piece both in strength and ductility. These experiments are corroborated by Table XIX-B, which gives a series of tests made by the Royal Prussian Testing Institute.* The average strength of the

TABLE XIX-B.

Welding Tests by the Royal Prussian Testing Institute.

Kind of metal.	Ult. strength; pounds per square inch.		Per cent. elongation in 200 m. m. =7.87 inches.		Per cent. reduction of area.	
	Av. 6 tests, natural.	Av. 9 tests, welded.	Av. 6 tests, natural.	Av. 9 tests, welded.	Av. 6 tests, natural.	Av. 9 tests, welded.
Medium O. H. steel	72110	41820	20.8	3.2	34.9	4.5
Soft O. H. steel	64570	45800	25.1	5.1	44.7	10.5
Puddled iron	57890	47080	22.2	7.7	39.5	14.0

welded bars of medium steel was 58 per cent. of the natural, the poorest bar showing only 23 per cent. In the softer steel the average was 71 per cent. and the poorest 33 per cent., while in the puddled iron the average was 81 per cent. and the poorest 62 per cent. Complete destruction of ductility is shown in the case of all three metals.

As above stated, the flat bars in Table XIX-A were such as had been used successfully in making pipe which would stand all ordinary tests of distortion, while the soft basic metal would meet the most severe tests. Such metal is used regularly where the best welding qualities are required, and the users are convinced that "the weld is perfect." It must be acknowledged that a weld as performed by ordinary blacksmiths, whether on iron or steel, is not nearly as good as the rest of the bar; and it is still more certain that welds of large rods of common forging steel are unreliable and should not be employed in structural work. Electric methods do not offer a solution of the problem, for the metal is heated beyond the critical temperature of crystallization, and only by heavy reductions under the hammer or press can much be done toward restoring the ductility of the piece. In many cases this subsequent hammering is impracticable.

* *Journal I. and S. I.*, Vol. I, 1883, p. 425, *et seq.*

SEC. XIXc.—*Influence of the metalloids upon welding.*—The way in which the impurities of the metal affect the welding power has been a matter of discussion, it having even been supposed that they act simply by interposition, and, again, that they increase the susceptibility of the iron to oxidation. I believe both of these theories are wrong. If the first were true, then one per cent. of carbon would have the same effect as one per cent. of sulphur, which is manifestly not the case. The second theory does not hold, since sulphur, notoriously one of the worst enemies of welding, is not oxidized either in the acid Bessemer or open-hearth furnace, and there is no ground for assuming that it oxidizes in welding. As phosphorus, carbon and manganese protect iron from burning in the Bessemer and open-hearth, so they must also tend to be preferentially oxidized in a blacksmith's fire, and thus by preventing the formation of iron oxide, as well as by the formation of a liquid flux containing phosphoric acid and oxide of manganese, they should, as far as oxidation is concerned, assist rather than retard the welding.

A third theory is that the impurities affect the mobility. When half of one per cent. of carbon is added to the metal, it produces a compactness or hardness, even when the steel is hot, that must prevent the easy flowing together that follows a pressure upon two pieces of white-hot wrought-iron or soft steel. A higher temperature cannot be used, because every increase in carbon reduces the safe working temperature at the same time that it increases the stiffness.

This decrease in mobility doubtless plays an important part in the explanation, but I believe a greater influence is to be found in what may seem at first sight to be the same thing, but which is a different quality, viz.: The power, or property, of passing through a viscous state on the road to liquidity. Other metals, lead and copper for instance, are malleable and ductile, but do not go through a history of slow softening under the application of heat, the change to a liquid state being sudden and without any marked intermediate stage. Pig-iron is of the same character, for no matter how low the other metalloids may be, the presence of three per cent. of carbon produces a metal which changes suddenly from a solid to a liquid state, and it is reasonable to suppose that each increment of carbon, phosphorus and manganese tends in the same direction.

In addition to this effect, I believe an equally important factor exists in the action of carbon, phosphorus, sulphur and copper in destroying the cohesion by increasing the tendency to crystallization, for these metalloids lower the point at which the steel becomes what is incorrectly, but quite naturally, called "burned." When steel is overheated it crumbles under the hammer, and it cannot be easily united to another piece when it is incapable of remaining united to itself. This theory also explains what seems to be a fact, that a small proportion of manganese aids in welding, for although it does decrease the mobility at any particular temperature, it allows a higher heat to be put upon the metal without destructive crystallization, and thus indirectly renders possible a greater mobility and maintains a more favorable molecular structure.

The following conclusions seem to fit the theory and the facts:

(1) With the exception of manganese in small proportion, the usual impurities in steel reduce its welding power by lowering the critical temperature at which it becomes coarsely crystalline.

(2) A small content of manganese aids welding by preventing crystallization.

(3) Only the purest and softest steel can be welded with any reasonable assurance of success.

(4) The confidence of a smith in his own powers and in the perfection of the weld is no guarantee that the bar is fit to use.

CHAPTER XX.

STEEL CASTINGS.

SECTION XXa.—*Definition of a steel casting.*—A steel casting must be made of steel cast in a fluid state into the desired shape. It has been the practice of some persons to make castings from pig-iron and steel melted in a cupola, although every metallurgist knows that the metal is altered very much by remelting, and that the changes in silicon, manganese and carbon depend on all the uncertain factors of temperature and exposure. In melting pig-iron, the carbon usually changes very little, for the content of this metalloid was adjusted in the blast furnace to about the absorptive capacity corresponding to the manganese and silicon, and as the conditions in the cupola are similar to those in the blast furnace, it follows that a metal which is the normal product of one will not be fundamentally altered by passing through the other.

But a mixture of steel and iron is not a normal product of any furnace, and in the cupola there is a tendency to make radical changes in the composition by absorption of carbon. Thus, by the unnatural union of pig and scrap, and by uncertain changes in silicon, manganese and carbon, there is produced a hybrid metal which is useful for special purposes, but which is fundamentally different from any kind of steel. It is true that scrap and iron are melted together to make open-hearth steel, but this is done under an oxidizing flame and, either during the melting or afterward, the metalloids are almost entirely eliminated, giving a definite starting point from which a known and regular metal can be made by the addition of recarburizers.

Sometimes castings of cupola metal, made either with or without scrap, are heated in contact with iron oxide in order to burn the contained metalloids. The product is a more or less tough metal, known as malleable iron, which is extensively employed in making small, thin, or complicated shapes that could scarcely be poured in

steel, but which can be made of the more liquid iron. The attempt has been made to call these "steel," and the claim has been fortified by analyses showing that the composition resembles that of some steel. On the same basis, the product of the puddle furnace or the charcoal bloomery might be termed mild steel. Malleable iron must always be inferior to steel, because any oxides of silicon, manganese, phosphorus or iron which are formed remain diffused throughout the mass. Such castings are useful in a certain field, for they are far tougher than cast-iron, and they may even enter into competition with steel castings, but they must always bear a different name, since steel castings must be made by pouring into finished shape the melted product of a crucible, a Bessemer converter, or an open-hearth furnace.

SEC. XXb.—*Methods of manufacture.*—The crucible process is sometimes employed for small castings, since the conditions of the "dead-melt" give a more quiet metal, evolving less gas in contact with cold surfaces, and the casting is more apt to be free from blow-holes. In special cases, as in the manufacture of big guns at Krupp's, the crucible has been used in making large masses of metal, but its great cost prohibits its adoption for general structural work.

Casting plants have been erected with Bessemer converters instead of open-hearth furnaces. These converters are small and the blast is introduced either on the side, just below the surface of the metal, or is directed down on the top of the liquid bath. For each system important benefits are claimed, notwithstanding the fact that Bessemer in his early experiments tried almost every way that could be thought of and abandoned them all for the one in general use today. Side blowing creates a greater amount of heat owing to the more perfect oxidation of carbon, and to the burning of a proportion of iron. In the ordinary converter much carbonic oxide (CO) escapes, but when the blast is introduced near the surface, and particularly when an auxiliary tuyere delivers air at a little distance above the bath, much of this carbonic oxide is burned to carbonic acid (CO_2).

In many "small" Bessemer plants the loss of metal is about 20 per cent. and in one case 30 per cent. This greater waste is partly in the cupola and partly in the vessels. The cupolas of a standard Bessemer plant are operated continuously for about three days, and

the iron lost from absorption by the lining or in dumping the bottom is small in proportion to the amount treated. In an iron foundry or a small Bessemer plant, the cupola works only a short time, and a considerable proportion of the iron is absorbed by the lining, while another large percentage is lost in scrap. In a standard Bessemer cupola the loss in metallic iron is only one-half of one per cent., while in intermittent cupola work it will be far above this figure.

In the standard converter with low-silicon pig-iron, the total loss is about 8 per cent., of which only 3 per cent. is metallic iron, about one-half of this (1.8 per cent.) being carried away as oxide in the slag and the remainder lost in shot and splashes. In the small converter it is necessary to use much higher silicon, and this gives a higher loss. A rough estimate of the waste under the two different methods is given herewith.

LOSS IN BESSEMER PRACTICE.

	Per cent. of metal.	
	Standard practice; bottom blast.	Small vessels; side blast.
Cupolas: Metalloids	1.5	2.0
Iron	0.5	3.0
Vessels: Metalloids	5.0	7.0
Slag (as oxide)	1.8	4.0
Shot and splashes	1.2	4.0
Total	10.0	20.0

The increased loss will cost about $2 per ton, but this is less than it would cost for fuel in a small open-hearth furnace running intermittently, to say nothing of the waste that will take place in open-hearth work. Small converters will give a very hot steel, although sometimes it is found necessary to add ferro-silicon at the end of the operation and continue blowing in order to get a higher temperature.

The disadvantages of the small converters are indicated by the slow progress in their introduction and the discontinuance of operation in plants already built. The Clapp-Griffiths process once

caused considerable stir, and yet in 1903 there was not a single converter of this type at work in America. Of the Roberts-Bessemer plants only two were active in that year. There were eight Tropenas plants at work, one Bookwalter converter and two vessels of special design. All these plants were making steel castings. The open-hearth furnace is the recognized agent for the making of steel castings. It allows control both of the composition of the metal and of the casting conditions. Most furnaces used for castings have an acid lining, but sometimes the hearth is basic. In the latter case there are more troubles and a somewhat greater working cost, but there is an advantage in the ability to use a poorer quality of scrap. Basic metal is more lively, and there is greater danger of honeycombs, but such metal is used to some extent in this country and quite extensively abroad, and it is economy to use the basic process when high-phosphorus scrap can be bought much cheaper than the selected stock called for by the acid hearth. It is currently supposed that the open-hearth furnace cannot make steel hot enough for small castings. This is a mistake, as in a proper furnace almost any desired temperature can be reached, and care must be taken to keep the metal from becoming too hot.

SEC. XXc.—*Blow-holes.*—The use of good stock determines to a great extent the nature of the product, but does not influence the solidity of the castings. This depends partly on the temperature and composition of slag and metal before tapping, and partly on the quantity and nature of the recarburizing additions. An increase in these latter agents covers up errors in manipulation, but shows itself in a higher content of metalloids. Honeycombed metal may arise from bad casting conditions or from a laudable desire to reduce the proportions of silicon and manganese, for the blow-holes decrease only slightly the strength and toughness of a casting, while the complete removal of them by overdoses of metalloids gives a brittle metal.

It is the current impression that all the difficulties in making sound castings have been overcome by the introduction of metallic aluminum and certain alloys of silicon. Great progress has been made, but there is no magic wand for sale which can be waved over a ladleful of steel to "kill" it "dead." Hadfield* says: "There is no rapid or royal road to the production of sound steel castings; this

* *Aluminum Steel. Journal I. and S. I.*, Vol. II, 1890, p. 174.

is only attained by long experience combined with specialized knowledge."

Some engineers specify that the cavities shall not exceed a certain percentage of the total area, but the common-sense method is to clothe the inspector with discretionary power, for a flaw may be harmless on the under surface of a base-plate when it would be fatal in the rim of a wheel. It should be noted that there is a radical difference between a "blow-hole" and a "pipe." The cavities often seen where the "sink-head," or "riser," is cut off are not evidence of unsoundness, but exactly the opposite, for they show that feeding continued after the riser was exhausted, and that the interior has been rendered solid at the expense of the surface.

SEC. XXd.—*Phosphorus and sulphur in steel castings.*—In specifications for steel castings, the important point is to state that phosphorus shall not exceed .04 per cent. Other elements may be guarded against by requiring a proper ductility, but phosphorus is often masked by other factors, and manifests itself only in that brittleness under shock which is its inherent characteristic. This is an important matter in the case of rolled metal, but is of more vital moment in steel castings, for these generally fail by sudden strain and shock.

The content of sulphur is of little importance, for it affects the cold properties very slightly, but it will do no harm to specify that it shall not be over .05 per cent., good castings generally containing less than this proportion. Copper need not be mentioned, for there is no evidence that it has any influence upon the finished casting.

SEC. XXe.—*Effect of silicon, manganese and aluminum.*—The elements used to procure solidity are silicon, manganese and aluminum. Their value to the steelmaker is due in great measure to their power of uniting with oxygen, the action being as follows:

8.44 parts manganese unite with 1.00 part of oxygen.
8.44 parts aluminum unite with 3.01 parts of oxygen.
8.44 parts silicon unite with 3.98 parts of oxygen.

Hence the aluminum is three times, and the silicon four times, as efficient as manganese, weight for weight, while they have an additional value from their greater affinity for oxygen, since this enables them to seize the last traces from the iron and wash the bath so much the cleaner.

Another function which may play a part in the operation is the increase in capacity to dissolve or occlude gases, and as far as the value of the casting is concerned this will be equivalent to destroying them. It is not known how far this determines the situation, but it is evident that it has no connection with the power to unite with oxygen. It was once thought that aluminum increased the fluidity of steel by lowering the point of fusion, but experiments with a Le Chatelier pyrometer* gave the same melting point of 1475° C. for ordinary soft steel as for an alloy with five per cent. of aluminum. The tendency of both aluminum and silicon is to make the steel sluggish; such metal will run through small passages without chilling better than ordinary steel, as the latter foams and froths when in contact with cold surfaces, and the flow is thereby impeded and sufficient surface exposed to chill the advance guard of the stream.

The percentage of manganese should not exceed .70 in soft castings nor .80 in harder steels, since more than this may render the metal liable to crack under shock. Silicon can be present up to .10 per cent. in the mild steels and .35 per cent. in the hard without any diminution in toughness. Aluminum is seldom present except in traces, and should not be over .20 per cent., for it decreases the ductility. The carbon must vary according to the desired tensile strength and the use to which the casting is to be put; when over .70 per cent. the steel becomes so hard that machining is slow, and there is danger of lines of weakness from shrinkage in complicated shapes.

SEC. XXf.—*Physical tests on soft steel castings.*—Since the failure of cast-work is almost always due to sudden strain, it is the safer plan to have the metal for common purposes between .30 and .50 per cent. in carbon, but when great toughness is required it should not be over .15 per cent. This latter specification also presupposes a low content of manganese, silicon, and, above all, of phosphorus; with this composition the casting displays all the characteristics usually associated with the toughest of rolled shapes. A test on an unannealed gear-wheel of such metal, manufactured by The Pennsylvania Steel Co., was made by cutting the rim between the spokes and then bending one arm to a right angle, twisting another through more than 180° without sign of fracture, while a

* See article on *Pyrometric Data*, by H. M. Howe, *Engineering and Mining Journal*, October 11, 1890, p. 426.

third was hot-forged from a star-shaped section of about 2 inches by 1½ inches into a bar 1¼ inches by three-eighths inch, and after being cooled was twisted into a closed corkscrew. Similar pieces were exhibited by Krupp in his magnificent exhibit at Chicago, but we stand ready in America to duplicate any such metal on regular contracts.

Such trials, made on castings taken at random, are preferable to tensile tests from sample bars, since the small pieces will not be in the same physical condition as the larger castings. A flaw or blow-hole in the small test does not imply that the casting contains similar imperfections, and while an open cavity which is visible on the surface of a machined test will have a disastrous effect upon the strength and ductility, it might be of slight importance if buried in the interior. This necessity of having a perfect surface makes it difficult to conduct a series of tests with the same dimension of test-pieces, for if five-eighths inch in diameter is the desired size, it may be necessary to turn some of the pieces to one-half inch, while the length must sometimes be reduced to 6 or 4 inches. It is also an argument against an 8-inch test piece, for the chance of pinholes and a consequent bad record is thereby multiplied four-fold.

This test piece should not be annealed unless the castings themselves are to be treated in the same manner, and although it is customary to anneal most structural work, it is not necessary in many cases if the best of stock is used. This will be called heretical by many engineers, but the tests just recorded upon an unannealed gear-wheel will show that the metal can be exceptionally tough in its original state. In castings of complicated shape and exposed to shock, annealing should be specified, but it must be remembered that there is no magic charm in this word. It is not sufficient to say that they shall be annealed and make sure only that they are covered with soot or fresh oxide. The heat treatment of steel is a scientific procedure, by which the metal is raised to an accurately determined critical temperature, whereby certain molecular rearrangements occur. If these rearrangements are properly guided, the result will be a fine-grained structure and a tough metal. If not properly guided the last condition may be as bad as the first.

Up to within a few years most steel castings were made of hard metal containing from .30 to .50 per cent. of carbon, and having a

tensile strength of 80,000 to 100,000 pounds per square inch, but as engineers have learned that the strongest bridge is not built of steel with .30 per cent. of carbon, so they must learn that it would be better to use a softer metal in castings.

TABLE XX-A.

Bars from Annealed Soft Castings and Unannealed Bars Rolled from 6-Inch Ingots, together with Bars from Large Ingots.

Steel manufactured by The Pennsylvania Steel Company.

Heat number.	Composition; per cent.				Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation; per cent. part in 8 inches, part in 6 inches.	Reduction of area; per cent.
	C.	P.	Mn.	S.				
3552	.17	.027	.65	.034	58190	34290	24.00	32.1
3555	.17	.027	.66	.056	56080	32440	14.90	19.7
3557	.17	.032	.60	.029	55880	32750	27.13	42.3
3559	.17	.027	.65	.033	55850	30350	23.10	42.5
3563	.17	.024	.62	.024	59890	34790	20.10	34.5
3565	.28	.029	.65	.025	60060	33180	20.05	26.8
3568	.14	.029	.70	.032	56820	31750	17.25	20.8
3571	.18	.033	.58	.028	56700	30670	26.88	46.7
3573	.17	.028	.67	.027	57440	31430	21.66	36.7
3573	.17	.036	.70	.027	56860	34260	22.04	29.8
3577	.17	.037	.59	.029	57980	33220	23.00	30.3
3578	.17	.045	.67	.026	56810	33510	22.16	30.4
3579	.15	.037	.68	.028	54940	32190	22.75	47.0
3580	.18	.038	.71	.017	58970	34180	22.25	36.7
3582	.17	.036	.68	.024	56880	31520	13.00	25.5
3583	.18	.032	.61	.022	59400	35330	14.13	18.8
3584	.18	.027	.60	.027	55970	29690	22.38	32.1
3586	.17	.027	.60	.027	55630	30300	18.50	31.4
3588	.16	.043	.63	.031	56050	32530	26.50	42.7
3592	.18	.027	.69	.028	59050	32940	20.00	33.9
Average of annealed cast bars.	.17	.032	.64	.029	57515	32564	21.12	33.44
2x⅝-inch bars rolled from 6-inch square ingots cast from the same heats and tested in natural state					63523	42700	24.74	42.80
Average of 2x⅝-inch bars rolled from 4-inch billets made from 16-inch ingots of 7 different heats of about the same tensile strength as the above castings.				Natural Annealed	62089 55021	42441 31576	20.14 30.36	60.86 60.00

Table XX-A gives the results of tests made on sample bars of cast steel, showing the composition and physical qualities. The silicon is not given, but it was below .05 per cent. in every case. The test piece was cut from a small coupon and this will explain why it was often necessary to pull the piece in a six-inch length. The

test was round in every case, and gave slightly worse results than a flat, but this is far from explaining the great inferiority of the casting when compared with the preliminary test, or the more marked difference from what should be expected in rolled steel of similar tensile strength.

TABLE XX-B.

Annealed Bars from Castings of Medium Hard Steel.

Manufactured by The Pennsylvania Steel Company.

Heat number.	Composition; per cent.					Ultimate strength; pounds per square inch.	Elastic limit; pounds per square inch.	Elongation in 8 inches; per cent.	Reduction of area; per cent.	Elastic ratio; per cent.
	C.	Mn.	P.	S.	Si.					
921	.20	.54	.026	.022	.30	60580 60680 60680 61480 62420	33710 32280 32750 30740 32460	30.50 36.50 36.00 32.00 33.00	38.57 51.90 44.34 39.80 50.90	55.6 53.4 53.8 50.0 52.0
953	.22	.56	.035	.034	.30	63320 64980 65500 65845 65980 67010	37400 34170 44950 33595 32290 49630	26.00 24.50 29.00 26.00 30.00 26.00	46.33 28.57 39.40 32.40 33.37 32.40	59.1 52.7 68.5 51.0 49.0 72.6
974	.33	.75	.029	.023	.35	72630 75240	44940 45980	16.00 28.00	20.70 31.68	61.9 61.0
966	.35	.68	.033	.034	.34	73090 75160	45390 45510	17.50 29.50	21.25 27.64	62.1 60.6

The results show what has been mentioned before—that the ultimate strength and elastic limit are altered very little by the amount of work as long as the piece is not finished at a low temperature. In the annealed casting the elastic limit is 56.62 per cent. of the ultimate strength, while in the annealed bars rolled from the ingot it is 57.39 per cent. This approximation is remarkable because the factors relating to ductility show that the physical state of the two metals must be radically different.

SEC. XXg.—*Medium hard steel castings.*—It has been shown that the average elastic ratio in annealed castings is about the same as in annealed rolled bars, but there will be greater variations between individual tests in the case of the unworked metal owing to local imperfections, and there will be greater variations with a stronger steel. This will be shown by Table XX-B, which gives the results on duplicate bars from four different heats of harder metal.

The ultimate strength is regular, and this indicates that the metal is homogeneous, but minute imperfections give rise to the variations in the elongation, reduction of area, and elastic ratio. In the body of a casting these defects exert little influence, but they affect the integrity of a small machined piece. The safest way, whenever practicable, would be to make a drop test on a sample casting rather than to cut a small bar from the piece or from a separate coupon.

PART III.

The Iron Industry of the Leading Nations.

CHAPTER XXI.

FACTORS IN INDUSTRIAL COMPETITION.

NOTE.—In 1899 I visited the large steel works of England, Germany, Belgium and Austria, and was received with unvarying hospitality. I trust that nothing here written will be more than fair criticisms of my hosts.

SECTION XXIa.—*The question of management.*—It is common in America to smile over the non-progressiveness of our foreign friends, and many people believe we are especially commissioned by Providence to illuminate the world with our spare energy. We must consider, however, that there is a vital difference between metallurgy abroad and metallurgy here. The direct management of a works in America has in the past had practically its own way, for the directors looked upon improvements as inevitable. As for the stockholders, they are not supposed to inquire into details. In England they rise at the annual meeting and ask questions as to the money spent on new work and the returns derived therefrom, and if American managers were subject to this inquisition they might live a less forceful life. In England, improvements are not made from profits, but new capital is authorized when deemed necessary. There are exceptions to this system, but it is the usual custom. An instance is the case of an English works in South Russia, having a capital of $6,000,000. During a period of eleven years annual dividends were declared, ranging from 15 to 125 per cent. In 1900, 20 per cent., or $1,200,000, was distributed, but as it was necessary to extend certain railway lines, bonds were issued for $750,000, or about one-half the dividend.

An English manager contends against strong labor unions. There was a time when such organizations regulated affairs in many American works, but it was found necessary to suppress them. In 1899 I found some new construction work going on in Middlesborough. The contractors stated that the boiler makers worked only three days each week, earning seven dollars per day, and then

began a four-day drunken carouse. In a short walk in that city I found a dozen men drunk upon the sidewalk. The labor unions will not allow any reform in the matter, as a man has a God-given right to get drunk. Much of this sentiment has been brought to America by the English and Welsh, but they have never controlled any extensive area in our country.

In England there is a tendency for the management of an enterprise to descend from father to son, and this must retard the advancement of progressive young men. There is also an opposition to change, a magnifying of every tradition into a law of nature, and a disinclination to be different from others. All these things tend to retard industrial progress.

In other directions America is behind. The retort coke oven is an instance, although it may be said that its introduction on the Continent was a necessity, as poor coals would not give a good coke in the beehive. Another case is the use of blast-furnace gas in gas engines, a field in which Germany is ten years ahead of America. The unfired soaking pit is in universal use abroad, but has been a failure in at least four works in America. It is found that acid steel does not work as well as basic metal in these pits, and, moreover, the rail steel of America is higher in carbon than that which is used for rails in Europe, and it is known that unfired pits do not work well with metal high in carbon. Nevertheless, the fact remains that the pits are in successful operation abroad, and are not used in America even on soft basic steel.

Every country has developed along its own lines. England has faced a lessening ore supply, decreasing both in quantity and quality and increasing in price. Germany has been driven to the basic vessel and has made it a success. In rolling mills our friends across the ocean have clung to the two-high reversing mill, sacrificing the possibilities of expansion in output that pertain to a three-high train. This capacity for expansion is the line between European and American practice. Taking railroads as an illustration, the lines that spread over the western half of our domain have been built within the memory of young men. The style of rail has always been fairly uniform, and in late years concerted action by manufacturers and engineers has resulted in one set of standard sections. In England, such standardizing seems impossible. One road is only two hundred miles long, and yet is laid with half tee

rails and half bullheads, so that each order for replaceals is half what it should be. The item of roll changes for small lots of material is very important to the manufacturer, and the railroad must pay the bill in the long run. It must be borne in mind that England cannot extend her domain, and it would be of doubtful expediency to build a counterpart of one of our American mills, which could alone make all the rails now produced in Great Britain. The two-high mill is better for small products and numerous roll changes, and has, therefore, been retained in England and on the Continent.

TABLE XXI-A.

Miles of Railway in Operation in 1902.

United States	66 per cent. of the total.	207,807
Germany		33,796
Russia		33,073
France		28,085
Austria-Hungary		24,106
Great Britain and Ireland		22,448
Canada		19,062
Italy		9,960
Spain		8,601
Sweden		7,692
Belgium		4,284
Europe except above		14,563
Asia		46,293
Other parts of the world		73,986
Total		533,65

This matter of small orders will be better understood by comparison of the mileage of railroads in the different countries, as shown in Table XXI-A. The United States has 40 per cent. of all the railroads in the world, Germany next with less than 7 per cent., and if we omit those nations that make their own rails and take all the rest of the world, including Canada, the total "markets of the world" do not include as many miles of track as are laid within our borders. Thus if we can assume that Germany, which ranks next to the United States in length of track, should monopolize the rail trade of the world with the exception of the United States, Russia, France, Austria, Great Britain and Belgium, each of which is self-supporting, she would not have as much tributary track as stretches out before the doors of American steel works. These reasons have influenced the development of rolling mills all over

Europe, and the newest plants have not copied America, but have enlarged and expanded the old two-high construction.

In making structural material and railway splices, it is the custom in America to cut the ingot into several blooms or billets and reheat for finishing, this being done in order that the bloom or billet mill shall run at its maximum capacity. In Europe little thought is given to this argument. The question everywhere heard is this: "What could we do with all the steel if we should run continuously?" It is therefore more common abroad to roll many different sections in one reversing mill, the stuff being finished in one heat from the ingot, the finished bar being very long; in one mill a 2-in. square billet is finished 475 ft. long and a 3 in. x 3 in. angle 425 ft. Oftentimes the finishing is done on a different mill, and frequently the finishing mill is three-high, the blooms being cut up and transferred without reheating.

The Germans use many three-high trains for finishing, and 15-inch beams are rolled directly from the ingot without cropping the ends and without reheating, the work being done by hooks and tongs without any machinery except a steam cylinder to raise the swinging support of the hooks used to catch the piece. Such a lifting motion is necessary when the rolls are 30 inches in diameter and the mill runs 110 to 120 revolutions. I have seen a mill of this size and speed handling 8-inch blooms weighing about 1200 pounds, and few American workmen would care to work as fast and as hard as these hookers, although American workmen would have smiled at the idea of a man being able to do anything when wearing wooden shoes. In rolling beams by hand in a train of that size an army of men is required, and the average visitor can hardly understand why some simple labor-saving devices are not introduced. It is related of an American at a German works that he offered to spend a certain reasonable sum in machinery and save so many dollars every month. The manager answered by showing him the cost sheets and proved that the total expenses for labor in the mill did not equal what he proposed to save. Such an answer cannot be true of all places where labor is thrown away. In one of the famous steel works of the world are two blooming mills, three-high, and exactly alike, turning out a combined product of ten thousand tons per month. In America one such mill would take care of from forty to sixty thousand tons per month and two men on each

turn would operate it, while in this place it took fourteen men on each mill. The fundamental difference was that the table rollers were not driven, and it would be safe to say that the introduction of machinery to drive those rollers would have paid back the money every three months.

At this place plans were drawn for an entirely new works, which involved immense expenditure of money, and it seemed the accepted law that an old plant should not be improved when a new one was contemplated. The reasons are self-evident, but in America such improvements do go on under exactly those conditions, because with high-priced labor and unlimited demand for steel it is often easy to pay for new apparatus in a year, while in Germany, with cheap labor and a smaller product, it would take a much longer time. At another works there were four mills under one roof, the building being large enough for handling and shipping the product of all the mills. The total output of these four mills was about 400 tons each twenty-four hours. In America the same outlay would produce from five to ten times that amount.

This condition, however, is not universal. It is impossible to obtain the same output from a basic converter as from an acid lined vessel, as the addition of the basic materials, the greater amount of oxidation to accomplish, and the much greater wear of the linings render it out of the question. Nevertheless there are several German works, like Rothe Erde, Phoenix, Hoesch and Hoerde, which make from 32,000 to 35,000 tons of steel per month from three basic converters ranging from 11 to 18 tons capacity.

The diversity of product in a German mill arises oftentimes from the control by syndicates of all the items of production, but it would seem difficult to get a mill up to its maximum efficiency with workmen who wear wooden shoes. It would be good business to pay for a leather outfit simply for the moral effect.

Some American writers and metallurgists ascribe the forwardness of steel manufacture in America to the ingenuity and brilliancy of a little group of men who lived a quarter of a century ago. It is an unkind act to disparage our predecessors, but I am actuated not by any personal feeling in expressing the opinion that no one man should be lifted upon a pedestal of fame unless the foundation

stones bear the names of many others almost if not quite equal to him in worthiness. It was the custom twenty years ago, as it is today, to pick out as an idol one who could deliver a witty after-dinner speech. Nothing is easier than to join a mutual admiration society and gradually have every member become in his own estimation more and more indispensable to the daily routine of the universe. American metallurgy has been developed by many minds, and these minds were not creators, but creatures; they were carried forward in the flood of "push," which is the predominant feature of our countrymen.

No spirit of rivalry has ever entered into European steel works. It is beyond question that many of the great advances that America has made have been due to vainglory and a simple desire to "beat all creation." Another factor was the desire to increase outputs when the margin of profits justified the most lavish expenditure, and it is doubtful if in every case it was foreseen that these outlays would result in such a decrease in the operating cost per ton. In foreign countries this argument of beating a competitor has no place. In one of the old works in Germany there are blast furnaces only 48 feet high, but as they show a fuel consumption of 1800 pounds of coke per ton of iron, the management sees no justification for starting on new construction. In our country we might keep such furnaces, but we would apologize for them; in Germany this sentiment is entirely unknown. Perhaps a little of the foreign spirit would be as valuable an acquisition for the American as a little American spirit is valuable for the European.

Each land has much to give to the other. Perhaps we can teach them how to work, but they can teach us how to save up just a little of our surplus energy and use it in enjoying the fruits of labor.

SEC. XXIb.—*The question of employer and employed.*—This is usually called the "labor question," and is spoken of in the same way that the consumption of fuel would be discussed, but although it may be convenient to treat it thus in books, it cannot be so handled in actual life. There are three distinct methods of arranging relations between the employer and the employed. The first is the paternal system, where the employer does everything for the workmen, as at Pullman in our own country, and at Creusot in France. This is probably the worst thing possible and breeds a

servile lot of men, whose highest thought is expecting the next spoonful of gruel. It is soup-house charity when there is no necessity for philanthropy.

The second method treats men as men. The self-respecting man does not ask charity; he wishes to pay one dollar for one dollar's worth of goods. This self-respecting man should be the one for whom all rules are made. He is a free agent, able to make his own contracts, to work or to leave, and as a rule he generally has a job and is too busy to make speeches on the labor question or kindred topics.

The third system is the labor organization where men bind themselves together and appoint a committee to get all they can for "labor." These unions declare that every man is the equal of every other man—when he is not; that a fast workman shall not be allowed to do any more work than a slow workman—which would seem to be an attempt to upset the decree of Providence; that a good workman shall not receive more than a lazy dummy—which is absurd; that labor-saving devices shall not be introduced unless the money saved is distributed among the workmen; and, worst of all, that dealings with the men shall be done through certain intermediary officers, when it is notorious that in some cases the men chosen to such office have gained power by cajolery, bribery and the lowest methods of ward politicians.

It must be acknowledged that the same class of men achieve political success under our system of popular sovereignty, and it would certainly be unwise to change our government to prevent the election of demagogues to office; but no demagogue nor Board of Aldermen is given authority over the freedom of the individual nor over great industries. The Czar of Russia might hesitate to order one hundred thousand men out of employment, and expose to mob rule great establishments and ruin the trade of a million people. Only one power in any civilized land has such authority, and this is a committee chosen by a small fraction of the community and often by a minority of the interested parties. It is of record that the disastrous decisions of such committees have often been condemned by the greater bodies of which they form a part, although such condemnation generally does about as much good as an apology for hanging the wrong man.

These faults are recognized by the labor unions themselves, and

many well-meaning persons advocate "compulsory arbitration" as the panacea for all ills; but it is impossible to see how a manufacturer can be forced to take orders and to operate his mill if he chooses to shut down. To compel him to do so would be condemnation of property, and the slightest consideration of fairness would lead the state or the community to make good any loss he might sustain by the continuance of operations. On the other hand, it is impossible to see how a workman can be compelled to work at any wage which is not satisfactory to him, when perhaps he is offered more elsewhere, and no manufacturer would ask for such an unconstitutional infringement upon the personal rights of his workmen. Moreover, the labor unions themselves, while anxious for a law to compel employers to abide by an award, recognize the injustice and the impossibility of forcing a workman to labor for less than he considers his due. It would therefore seem that the best way is the simplest: it is to let each man exercise the rights given him by our laws of working for the highest wage he can get, and of leaving when he is not treated rightly.

Under the system of labor unions the men who perform some particular line of work may often be entirely unrepresented on the committee. The works with which I am connected has in operation seven rolling mills and each one is different, both in amount and character of product. In some of these mills there are over thirty different kinds of positions where the men are paid by the piece or ton, not counting the work done by the day or hour, and each of these positions has a special rate. Under any system of committees the great majority of positions will have no representative, and there will always be an incentive on the part of a committeeman to look after his own job and his own friends, while the management of the works will be only too glad to give such a committeeman anything he may ask if he will agree to a low rate for those not present at the conference. A few years of such work will generally bring on a strike, and well-meaning humanitarians will then advocate "arbitration," by which is meant a reference to some men who do not know a pair of tongs from a straightening press, and who will recommend that the difference be split, the question of disproportionate rates being left as it was. To what extent this disproportion can obtain has been shown by sworn testimony before a Congressional committee, where it was proved that men who joined

the disastrous strike at Homestead drew thirty thousand dollars a year.

It might be of advantage to pay still higher bribes to the leaders of the workmen, since such wages for rollers cannot be called earnings, if it were not for the fact that there is a limit to what the members of a union will stand, for it is necessary to keep in mind that the action of the committee is not final. The signature of the company bears with it the highest responsibility, but the signature of the committee is worthless. It may or may not be agreed to by the union, but whether it is or is not, the decision does not carry with it the slightest financial responsibility. It does not bind and cannot bind any individual to work for the company a day longer than he chooses, and if the industrial situation brightens and men find more remunerative employments it is the privilege of each and every man to leave, and if they choose to go out on a sympathetic strike there is no redress for a violated contract.

I do not believe in such inequitable arrangements, nor do I believe in arbitration on many of the questions arising, or in a system of committees so organized. I believe that each man who thinks himself ill treated should have access to the office of the manager. It is the right of appeal to a higher court, and it is the rare exception that a body of men appear to discuss a question unless there is some ground for their action. Investigation generally shows that their statements are correct, and while the workmen are trying to get all that they can, and while the manager is trying to give as little as he may, the level-headed men generally lead in the argument, a fair and equitable arrangement can be made, and no man feels that he is outwitted by a committeeman. He has stated his case; he has heard the reply; he remains a free citizen to accept the offer or to decline it, and no works can long operate if the offer is not just and right.

There may be cases where different conditions govern and where large bodies of skilled men of one trade may join for mutual protection; but in a steel works where hardly any two positions are alike, either in nature of work or in rate of pay, the labor organization as at present constituted has no place. Moreover, under no condition will it ever be more than an unworthy and petty factor in the universal labor problem until it gives up once and for all the tenet it now holds to be fundamental, that a limit of production

should be set for each man. If labor unions will drop this primal error, reason may find a basis for discussion, while with this dictum as a premise there can be no reconcilement with the spirit of progress. They must also drop the tyrannical theorem that non-union men may not work with union men, and the anarchistic conception that non-union men must not deliver goods to union shops. Many modern strikes are based on these ideas, and arbitration is utterly out of the question since the answer is either yes or no. Any board of arbitrators, by the mere act of considering such claims, thereby acknowledge that they have a standing in equity, when a moment's consideration will show that they subvert the principles of our government. Almost all of the large steel plants of America manage their own affairs. The result is that the introduction of labor-saving devices creates no trouble, the more so because such devices, while they decrease the number of men, demand a higher grade of workmen, so that it often happens that the man who operates the new machine will earn a higher rate of wages than any man made before at the same kind of work. Another reason why labor-saving machines are not entirely contrary to the interests of the skilled workman lies in a fact which seems to be unknown to the average social economist. In the manufacture of steel, there is much hard and heavy work. Formerly, when the work was done by hand, a skilled man was one who was superior physically, and as soon as he reached middle life he was obliged to accept some less arduous and less remunerative employment. With the introduction of machinery the skilled employee may often retain his position during the remainder of his life, and the ability to keep an old and trusted employee in a position where his experience is of value to himself and to his employer is not merely a question of sentiment; it is an advantage as great to the employer as to the workman.

The argument in favor of labor unions may be stated thus:

(1) Capital is allowed to organize;

(2) Labor must have the same rights as capital;

(3) Labor must be allowed to organize.

It is impossible to dissent from the premises, or to escape from the conclusion; but it is necessary to define the terms. It is essential to know just what is meant by "organize." Capital organizes into corporations, but the rights and privileges of these bodies are regulated by law. They may not overstep whatever regulations

may be made, and the people can make or change these rules. In only one case in America can a corporation interfere in any way with the private rights, property or freedom of the individual. That exception is the right of eminent domain, and the conditions under which this right may be exercised give to every injured party more than sufficient compensation for the trespass. Nevertheless, it is an infringement of a personal right, and for this reason such corporations have always been regarded as subject to legislative control. This control has not been entirely theoretical, for some socialistic Western States have enacted laws that have brought ruin to all the capital invested.

Taking into consideration simply manufacturing corporations as the only ones pertinent to our inquiry, in no particular do their corporate rights allow any trespass upon the rights of individuals. They may use their money to injure men or communities, but so may any private person. Any multi-millionaire might buy a factory and shut it down and ruin a village, and it is difficult to see what could be done about it. He might discharge all his old and trusted servants and the law could hardly touch him. He might commit all the sins charged against corporations and there would be no redress. It is wrong to condemn corporate laws for allowing acts which a private individual may legally do, and it is certain that manufacturing corporations have been given no rights of eminent domain, no privilege to infringe upon the private estate of the citizen. They have the power to issue bonds, to issue stock, to conduct business under a perpetual name, and in return have certain duties, certain taxes to pay, certain regulations under which they must conduct their business and protect the interests of the minority. This is the extent of their powers as granted by the State. All other powers are inherent as vested in general constitutional prerogatives.

This, then, is the definition of "organize," and the right of men, whether so-called "laborers" or not, to so unite has never been questioned. They may form organizations for pleasure, for improvement or for business; but it is another matter when they "organize" to restrict personal liberty. That a band of men may agree among themselves not to work more than a certain number of hours per day is as certain as that they may agree not to smoke, or not to eat meat. Their right to do so is unquestionable. It is their

privilege to agree that they will only handle two shovelfuls of earth per hour, or one shovelful per day. It is their right to refuse to work for less than five dollars per day or twice that amount. It is their right to ask their employer to sign a scale and agreement to that effect for one year or ten years, but it is also the right of the employer to ask what guarantee is given that they will stay in his employ, and it is also his inalienable right to tell them that such agreements are not according to his wish and that he will try and get men who will work without them; and if such "organization" should reach the last stage and the "organizers" should demand that no one should work in the shop except those subscribing to the union and paying the salaries of the officers, the only possible answer is that such a rule is contrary to the fundamental tenets on which this government rests.

Certain matters cannot be arbitrated. Thus it is of record that a certain "union" works in America was shut down several times, not on account of any disagreement between employer and employee, but on account of disputes between two rival labor unions. It is quite comprehensible why under such conditions a manufacturer might conclude to employ only non-union men. His right to do so is as unquestionable as the right of a farmer to employ only colored laborers or to employ only white men, or to employ both. Granting that the manufacturer has concluded to run non-union, it is impossible to submit the matter to arbitration. If his conclusion is unwise, he will suffer most, for if men will not work for him then he will lose money, and if he can get only the scum of the streets then also will he lose; but if he can obtain good men in sufficient numbers, then it is quite certain that the conditions are acceptable to them and to him and that his position is just and equitable.

It is impossible to conceive how a decision to employ only non-union men can be susceptible to arbitration, and it would seem unnecessary to more than state the theorem were it not that politicians and certain lecturers at Chautauqua are advocating compulsory arbitration. It must always be remembered that no employer ever entertained a prejudice against a labor union on general grounds alone. The opposition arose from the plain fact that labor unions regularly develop into the most tyrannical and outrageous violators of individual rights. It has happened many times that a hundred union men have left a shop because one non-union man

was at work. Is it possible that any employer with a grain of self-respect, or any intelligent person, will say that such a matter is open to arbitration? Our common law recognizes prosecution and imprisonment, but it recognizes the arbitration of crime as the compounding of a felony and calls this a crime in itself.

The proposition has been made by a President of the United States that employers should not discriminate against union men, but that union men on the other hand should not interfere with non-union men working beside them. This is a most excellent solution from an academic standpoint, but in nine cases out of ten where such an arrangement is attempted it is overthrown by the union element, and in places where the troubles have developed into riot and murder we have yet to hear of any assistance given by labor leaders to the legal authorities to punish the instigators of crime.

Labor organizations are a form of socialism. In the same category stand the paternal laws of Germany and the less radical measures proposed or enacted in our own land. This fact does not necessarily brand them as wrong, for socialism may contain elements of right and justice. I do not make the senseless generalization that, since trades unions are socialistic and socialism wrong, therefore the unions are wrong; but if socialism is right, it is right for all; there must be no classes in America. There is no stone wall between the humblest laborer in a steel works and the manager. The pathway is wide open from the workshop to the sanctum of the administrative head. The rule that applies to one must apply to the other. If eight hours is the maximum time for the laborer, then the same law must govern the manager. If the humblest workman must not *work* except within certain hours, then the manager must not *think* except during the same interval. The mechanic must not go home and think how a job can be done better, the superintendent must not improve the plant, nor make more steel today than yesterday. Moreover, if no man is to do work except at his own trade, then no man must work in his own garden, raise his own flowers, or mend a broken fence. Such is the inevitable logic of the labor union.

The labor leaders will hardly wish to say that there are classes and castes in America, and if there are no classes then the same rules should govern all; and if these rules are to be made for all,

then they must be laws, made by the regular law-making bodies; made by the people through their chosen representatives. This has been done in New Zealand; it may be well to await the result.

In this great experiment success will not be measured solely by freedom from strikes, for the industrial peace compelled by arbitration is not necessarily the best thing, any more than political and social peace compelled by the superior force of an autocratic monarchy betokens the highest triumph of government. The excitement of a political campaign in America is more desirable and more truly an exponent of a healthy condition than the sullen passivity with which servile subjects might view a change of masters. The current views of many political leaders in interfering with industrial freedom resemble the medieval notion that a decree of the king could fix the price of wheat, prohibit the export of gold, or exalt the value of a debased currency. Success or failure cannot be determined by immediate effect; some people imagine that when the arbitration laws of New Zealand have prevented a strike by the easy method of splitting the difference, a great triumph has been won. They forget that this is a backward step; that it is abandoning the business method of fixing a price, and substituting the ancient Jew practice of asking twice as much as is expected in order that an intermediate price may be secured. If the public supposes that the truth is a compromise between extreme demands, it is easy to keep business in a ferment by asking for an advance.

It will take a generation for New Zealand to discover the result of her innovations, but even at this early day the situation is not entirely happy. The employers in three provinces have come out strongly against the present system of compulsory arbitration, while the labor union of one of these provinces is up in arms at the unexpected phenomenon of an award against the workmen, and the Labor Council is asking "why should we obey an adverse award, when no jail is large enough to hold us all?" Not until the regulations made in this distant island have had time to produce their proper fruit, not until New Zealand becomes thickly settled and possessed of the complex industrial life existing in those countries which are factors in the business of the world, not until the new schemes of labor regulation have proven their efficacy under international competition, can the laws of this much-discussed country

become more than an interesting experiment to be watched rather than to be copied.

SEC. XXIc.—*The question of tariffs.*—In the minds of many of my readers this discussion will not be complete if I do not record my belief that the present condition of the American iron manufacture is solely due to the operation of the high protection system. Let me say, therefore, that some men in the iron trade do not believe that the entire business of this country is represented by a tariff measure, just as on the other hand there are men not connected with the iron business at all who fail to appreciate that the tariff is robbing them of their last cent. During the period that high tariffs have been in force our iron industry has expanded to most wonderful proportions, but that such expansion is due to the tariff is not a necessary conclusion. That such expansion has from time to time been interrupted by periods of panic and disaster is unquestioned, but it is rash to say that such disasters are the inevitable results of protective tariffs.

It is true that American manufacturers have sometimes sold a part of their products to foreign customers at a lower price than the ruling market quotations at home, and this fact is immediately grasped and spread broadcast by petty politicians and by so-called economists, who seem always to be climbing out on the scale beam in one direction as far as they can go to balance the equally erratic high tariff promoters who are climbing the other way. Nothing can so quite keep in countenance the fallacies of fanatics as counter fallacies gravely argued. Nothing could more please the advocates of free trade than to see protectionists trying to prove that iron ore is not raw material. My mind is not broad enough to grasp all the complex conditions that surround the industrial progress of America, and I cannot see as clearly as some men that no steel would ever have been made here had it not been for certain divinely inspired orators in Congress; neither can I see as clearly as others that the nation would have been richer and greater had no duty ever been imposed on foreign manufacturers. It is possible that the reason why I cannot see so clearly is that my information is gained at first hand, and is not made up of partisan statements. An able and honest President of the United States publicly announced that a tariff was a tax, and that the price of an article here was the price abroad plus the tariff. If the statement concerning the price

had been true, then undoubtedly the tariff would have been a tax, but, unfortunately for the reputation of the said President, the statement was not true, as he might easily have found and should have found by the most casual inspection of the regular trade papers. In the case of steel rails, for example, the price in the United States is not equal to the foreign price plus the tariff, and has not been for fifteen years, while there have been many times when they were sold here much cheaper than they could be bought at European works.

Such free trade nonsense is matched by many protectionist pamphlets declaring that high tariffs mean high prices and high wages, when on the one hand we have seen the United States selling steel cheaper than any other country in the world, and we may see Austria and France, both high tariff nations, paying starvation wages to their work-people, and using women in great numbers as laborers in the roughest kinds of work.

The following conclusions may be wrong, but I trust they are not fanatical or entirely unfounded:

(1) A high tariff on a certain article hastens very much the establishment of factories to produce that article.

(2) The establishment of a new industry like making steel, cotton or woolen goods, carpets, etc., etc., requires at least ten years before all the social and industrial conditions have become so correlated that the cost of production reaches an economical footing.

(3) During this period the general public pays a somewhat higher price for this article, the excess depending on the amount of protection and the amount of domestic competition.

(4) In some cases and in industries not requiring very large investments of capital or the creation of communities of special workmen, this period during which the public is so taxed may be very short, and the price may soon drop even below that paid to foreign manufacturers.

(5) If the profits to the protected manufacturer are large, new works will be erected, and if these combine to extort an unreasonable profit, still other works will be built, the end being the same in any event in that the needs will be met and internal competition ultimately bring about a price representing in the long run not much over a fair profit.

(6) Whether this price, the cost plus a fair profit, is or is not

more than the price abroad will depend upon the natural advantages of the situation. If an article cannot be made here as cheaply as abroad, then the question must be answered whether the public should pay the premium. If it can be made as cheaply, then competition will force it to be so made.

(7) The "price abroad" is a term which must be used carefully, for the price at which standard articles can be bought from time to time for delivery beyond the borders of the home market does not in the least represent what would be the price under a greater demand; such a demand, for instance, as would be made on Germany and the United States if all the steel works of England should shut down. Neither do these quotations represent the real cost of manufacture.

(8) The real cost of manufacture includes many things which are usually overlooked, but which are of immense importance. The main items are as follows, it being assumed for the sake of simplicity that a steel works owns its own ore and coal mines and coke ovens:

(a) Actual operating costs at all mines and works, including labor, fuel, repairs, etc., etc.

(b) Freight charges on all raw materials and incidentals.

(c) Interest at 6 per cent. on all money actually invested in mines and plant, and on all floating capital needed to carry on the business.

(d) Expenses incident to superintendence, selling agencies, taxes, bad debts, pensions, damages, etc., etc.

(e) Depreciation, by which is meant a class of items generally overlooked. The ore and coal must bear not only the interest on the money invested, but a sum sufficient to pay for an equal quantity of material when the beds are exhausted. The depreciation of the steel plant itself is still higher, for it is almost safe to say that to keep a steel works up to its value, to keep it as a factor in the great strife of competition, requires an annual expenditure of ten per cent. of its cost. Engines, boilers, rolling mills, cranes, shears and all the manifold equipment may last that time, may last longer, or may be outlawed before that period expires. A mill not up to date cannot compete with one that is, and if it cannot compete, then it loses money; and if it loses money, then it is worth nothing, absolutely nothing, no matter how new it is or how much it cost.

(9) This item of depreciation is often represented on the cost sheets by new equipment and machinery, but sometimes these are erroneously or falsely put into the capitalization account. Whether ten per cent. is or is not the correct figure for a steel plant, it is quite certain that a very considerable amount must be included in the true cost of manufacture.

Assuming that the plant cost ten million dollars, a depreciation of ten per cent. is equal to one million annually; and if the production during the year is five hundred thousand tons, then this charge amounts to two dollars on every ton of steel made. It may be more in some works and may be less in others.

(10) When business is slack it is necessary that the manufacturer ignore this item altogether, for he will assuredly operate his plant if he can cover his actual running expenses. If, therefore, he does not earn his depreciation during a period of one, two or three years, then he must earn a double amount for an equal period when good times return, and this must not be considered as profit. He must also ignore the interest on the money invested in plant and in floating capital, as well as the expenses of selling agencies, taxes, insurance, etc., since all these items, like depreciation, will go on whether steel is made or not.

(11) During this era of low prices, the actual cost sheets and the annual reports may show no loss or even a margin of profit, and the average observer might conclude that these figures represent the proper selling price, a conclusion which would be entirely erroneous.

(12) It is the part of common sense for rival manufacturers to get together and agree to prevent cutthroat competition, by which not only are all profits thrown away and all depreciation and interest charges ignored, but even operating costs encroached upon. A fair price under such an arrangement would include depreciation and interest as fundamental parts of the cost.

(13) Having made such an agreement for home trade it becomes good policy to ignore these items on competitive business for foreign deliveries, since they are both fixed quantities, not depending on the amount of steel produced, and the extra output caused by such foreign deliveries cheapens the cost to the manufacturer. Moreover, certain lines of foreign trade cannot be held if prices are varied with every local advance. Having secured, for instance, the business of a certain railway in Australia, it is evidently quite impossible

to retain it if the price quoted follows every boom in the home market; and it is certainly good policy to keep the trade of this railway for future business, in spite of the hue and cry about lower prices to foreign buyers.

(14) This argument is not new, but has been an accepted commercial and industrial maxim in every country, under both protection and free trade, and all the "prices abroad," so freely quoted, are based on this rule as existing in foreign lands. It is even true that bounties are actually paid in some instances to encourage export trade.

(15) The payment of a bounty for export trade is directly in line with the maintenance of a protective duty after the incubative period has passed. Practically it must be looked upon as out of the question owing to the impossibility of arriving at a complete knowledge of just what would be equitable, but although such a system would breed many wrongs, it is theoretically justifiable to a certain limited extent.

A steel works, in common with every manufacturing plant, is a benefit to the general public in many ways. It contributes to the payment of taxes and thus saves an equivalent amount of individual expenditure. It is the foundation of large communities which influence and increase the general prosperity of the country by giving a market for all kinds of commodities. It supplies freight to the railroads in enormous quantities, and brings an enormous income to the railroads, the gross receipts from a steel works being four or possibly six times as much as though a similar amount of material were imported from abroad, and there were no raw materials or incidental supplies to assemble. The cost of moving other freight is reduced by this increased business, and the establishment of other industries thereby made possible, which, in turn, react by further lowering the cost of transportation by their contribution to tonnage moved.

A nation would lose no money if a bounty were paid to support manufactures, provided such support were necessary, and provided that the bounty did not exceed the sum directly and indirectly paid or saved by the manufacturer to the state and to the public. If German steel is laid down in England at one shilling per ton cheaper than English steel works can make it, and if that shilling represents the dividing line of business, then it would be money in

the pocket of the taxpayers of England if a protective duty of one shilling were levied upon foreign steel, since the amounts contributed by works in operation must be much more than this. It is impossible to give the upper limit of such a tariff, for the conditions are too various and include all the correlated conditions, down to the higher value of farm products in industrial communities. Within this range, whatever the limits may be, a protective tariff is not illogical; beyond the limit, it is uneconomical.

Such are my opinions. They may not embrace absolute truth. Few things have ever been written that were beyond need of change, but it has been deemed advisable to revise the first chapter of Genesis and it is barely possible that some alteration may be necessary in the Wealth of Nations by one Adam Smith.

CHAPTER XXII.

THE UNITED STATES.

SECTION XXIIa.—*General view.*—It is impossible to survey the iron industry of the United States as thoroughly as those of the nations of Europe will be discussed, for our country is entirely out of proportion to the scale by which other countries are considered. For instance, the State of New York is not only left undivided in current statistics of the iron industry, but is combined with New Jersey, and yet the iron and steel business of the State is made up of two parts, entirely independent of each other. In the northeast are the mines of Lake Champlain, and in the extreme west the furnaces of Buffalo smelting Lake Superior ores. These two districts have no relation to each other and are 250 miles apart; farther than the mines of the Cleveland district from the coal of Cardiff; as far as from Prague, in Bohemia, to Gleiwitz, in Silesia. In the same way Virginia is considered as a whole, although it covers an area as great as England; it is not regarded as a great center of pig-iron production, but it makes half as much as Belgium and nearly double the output of Aachen and Ilsede combined.

The distinctive feature of the American iron industry is the great distance through which raw material must be carried. In Europe a haul of 200 miles is long and the cost excessive, while in America it is not unusual at all. Coal and coke are carried as far as this in several instances, while Chicago draws its furnace fuel from 500 to 600 miles. In the publication of the American Iron and Steel Association a magnificent disregard of distance combines the outputs of Colorado and Missouri, which are 800 miles apart; as far as from Paris to Warsaw. The statistical reports of America are quite full in respect to the product of pig-iron, but the data on steel are unsatisfactory owing to the desire for secrecy on the part of some manufacturers. Table XXII-B gives the production of steel from 1867, while Table XXII-C shows the different kinds of

steel made in both the United States and Great Britain, and Table XXII-D the percentage of each product.

In 1867 the production of Bessemer steel in the United States was 2679 tons. Some small quantities were made before this, but the industry was put on a permanent footing by the establishment of an entirely new Bessemer plant at Steelton, Pa., a plant which has continued to make steel from then until now. This was followed in the same year by Troy, while Cambria, at Johnstown, was the next to enter the field. From 1867 to 1871 about 20,000 tons

TABLE XXII-A.

Output of Pig-Iron and Steel in 1901 in the United States.

See text for boundaries of districts; thus "Pittsburgh" includes parts of three States and output of pig-iron for "Steelton" includes two counties.

	District.	Blast Furnaces.		Pig Iron.		No. of works having rolling mills.	No. of works making crucible steel.	Bessemer Converters.			
								Small, mostly for steel castings		Standard size 7 to 20 ton.	
		Coke.	Charcoal.	Output; tons.	Per cent. of total			No.	Average capacity.	No	Average capacity.
1	Pittsburg	82	.....	6,880,000	43.3	137	17	.....	.....	30	10
2	Illinois	20	.....	1,597,000	10.1	21	2	3	2	5	11
3	Alabama	39	6	1,225,000	7.7	10	....	.....	.....	.....	.....
4	Cleveland, Ohio	8	.....	783,000	4.9	15	....	.....	.....	4	11
5	Steelton, Pa	18	.....	695 000	4.4	12	....	.....	.....	3	10
6	Johnstown, Pa	6	.....	512 000	3.2	3	....	.....	.....	4	12
7	Lehigh Valley, Pa	29	.....	481,000	3.0	11	1	.....	.....	4	7
8	Southeastern Pennsylvania	17	1	478,000	3.0	36	3	5	2	.....	.....
9	Virginia	22	4	449,000	2.8	6	...	.....	.....	.....	.....
10	New York and New Jersey	27	3	439,000	2.8	38	8	.....	.....	.....	.....
11	Tennessee	15	1	337,000	2 1	2	1	.....	.....	.....	.....
12	Hanging Rock, Ohio	11	8	309,000	2.0	4	....	.....	.....	.....	.....
13	Sparrow's Point, Md.	4	.....	303.000	1.9	6	...	.....	.....	2	20
14	Wisconsin and Minn.	6	1	208,000	1.3	7	4	3	2	....	.....
15	Colorado	3	.....	185,000	1.2	2	....	.....	.....	2	5
16	Michigan	.....	9	171,000	1.1	6	....	2	2	.....	.....
17	Other parts Penn	17	3	398 000	2.5	45	2	.....	.....	.....	.....
18	Other parts Ohio	9	.....	301.000	1.9	27	3	1	1	2	4
19	Kentucky	8	.....	68 000	0.4	9	...	.....	.....	2	5
20	Missouri	1	1	18,000	0.1	5	....	2	2	.....	.....
21	North Carolina	2	.....	27,000	0.2	...	....	.....	.....	.....	.....
22	Georgia	1	4								
23	New England	.....	7	12,000	0.1	15	3	2	2	.....	.....
24	Indiana	.....	.....	.....	.....	28	1	.....	.....	.....	.....
25	Delaware	.....	.....	.....	.....	7	....	.....	.....	.....	.....
26	Other States	.....	6	2,000	.....	8	...	1	2	.....	.....
	Total	345	54	15,878,000	100.0	460	45	19	.....	58	.....

TABLE XXII-A.—Continued.

	District.	Open Hearth Furnaces.						Steel; all kinds.	
		Acid.		Basic.		Steel castings not included in foregoing.			
		No.	Average capacity.	No.	Average capacity.	No.	Average capacity.	Output; tons.	Per cent. of total.
1	Pittsburgh	35	30	84	40	20	18	(7,317,000)	54.3
2	Illinois	3	25	9	40	13	15	1,760,000	13.0
3	Cleveland, Ohio	3	25	10	30	2	10	870,000	6 4
4	Johnstown, Pa	2	35	8	40	2	4	656 000	4.9
5	Southeastern Penn	12	30	33	40	14	20	629,000	4.7
6	Steelton, Pa	3	45	9	40	2	15	427,000	3.2
7	Sparrow's Point, Md	.....	.....	.....	.....	.....	.....	352,000	2.6
8	Scranton, Pa	.....	.....	.....	.....	.....	.....	352,000	2.6
9	New England	5	15	6	40	6	15	173.000	1.3
10	Alabama	.....	.....	13	45	1	20	(150 000)	1.1
11	Colorado	.....	.....	.....	.....	.....	.....	(150,000)	1.1
12	New York and New Jersey	2	25	8	20	10	10	107,000	0.8
13	Lehigh Valley, Pa	6	30	2	40	.....	.....	69,000	0.5
14	Missouri	.....	.....	.....	.....	3	20	(50,000)	0.4
15	Hanging Rock, Ohio	.....	.....	4	30	.....	.....	15,000	0.1
16	Other parts of Ohio	4	11	.....	.....	15	15	165.000	1.2
17	Other parts of Penn	4	20	3	15	4	15	53 000	0.4
18	Tennessee	.....	.....	.....	.....	1	3		
19	Wisconsin and Minn	1	20	3	15	3	20		
20	Michigan	1	15	.....	.....	.....	.....	(189,000)	1.4
21	Kentucky	1	7	7	25	.....	.....		
22	Indiana	1	30	1	30	7	20		
23	Delaware	1	50	4	50	.....	.....		
	Total	84	.....	204	.....	103	.....	13,474,000	100.0

per year, or about half the steel made in the country, was made by the Bessemer process, and all of this went into rails. From 1872 to 1874 the annual production was about 140,000 tons, all of which was rail steel, and this represented about three-quarters of the steel output. From 1875 to 1879 the output of Bessemer increased five-fold over the period just previous, and averaged 560,000 tons per year. A great part was made in the eastern portion of Pennsylvania, at Steelton, Johnstown, Bethlehem and Scranton; but the then new works of Edgar Thomson, at Pittsburgh, and the plants at Chicago and Cleveland had become factors of great importance. The Bessemer output during this time was 88 per cent. of the steel output of the country and all of it was rolled into rails.

From 1880 to 1882 the output more than doubled and almost all was put into rails. During this period there was a marked increase

TABLE XXII-B.

Output of Steel in the United States from 1867 to 1904.

Year.	Bessemer Ingots.	Open Hearth Ingots.	All Kinds of Steel.	Bessemer Rails.	Bessemer Steel; per cent. of total Steel.
1867.....	2,679	.....	19,643	2,277	14
1868.....	7,569	.....	26,786	6,451	28
1869	10 714	893	31,250	8,616	34
1870.....	37,500	1,339	68,750	30,357	55
1871.....	40,179	1,785	73,214	34,152	55
1872.....	107,239	2,679	142,954	83,991	75
1873.....	152,368	3,125	198,796	115,192	77
1874.....	171,369	6,250	215,727	139,414	79
1875.....	334,253	8,080	389,799	259,699	86
1876.....	469,639	19,187	533,191	368,269	88
1877.....	500,524	22,949	569,618	385,865	88
1878.....	658,778	32,255	731,977	491,427	89
1879.....	829,439	50,259	985.273	610,682	89
1880.....	1,074.262	100,851	1,247 335	852,196	86
1881.....	1.374,247	131,202	1,588,314	1,187,770	87
1882.....	1,514.687	141,341	1.736.692	1,284,067	87
1883.....	1.477 345	119.356	1,673,585	1,148.709	88
1884	1,375,531	117,515	1,550,879	996,983	89
1885.....	1,519,430	133,376	1,711,920	959,471	89
1886.....	2,269,190	218,973	2,562,503	1,574,708	89
1887.....	2,936,033	322,069	3,339,071	2,101,904	88
1888.....	2,511,161	314,318	2,899,440	1 386,277	87
1889.....	2,980,204	374,543	3,385,782	1,510,057	87
1890.....	3,688,871	513,232	4,277,071	1,867,837	87
1891.....	3,247,417	579,753	3,904.240	1.293,053	83
1892.....	4,168,435	669,889	4,927.581	1,537,588	85
1893.....	3,215,686	737,890	4,019,995	1,129,400	80
1894.....	3,571,313	784,986	4,412.032	1,016,013	81
1895.....	4,909,128	1,137,182	6.114.834	1 299,628	80
1896.....	3,919,906	1,298,700	5,281,689	1,116,958	74
1897.....	5,475,315	1,606,671	7,156,957	1,644,520	77
1898.....	6,609,017	2.230,292	8,982.857	1,976,702	74
1899.....	7,586,354	2,947,816	10,639,857	2,270,585	71
1900	6,684,770	3,398,135	10,188,329	2,383,654	66
1901.....	8.713.302	4.656,309	18,473.595	2.870,816	65
1902.....	9,138.368	5,687.729	14,947.250	2,935,392	61
1903.....	8,592.829	5,829,911	14,534.978	2.946.756	59
1904.....	7.859,140	5,908,166	13,859.887	2,137,957	57

in open-hearth steel, a start having been made at the New Jersey Steel and Iron Co. in 1868, but it was not until 1880 that the output reached 100,000 tons per year. Up to this time the steel industry was largely dependent upon Spanish ores, and the works near the eastern seaboard were in the most advantageous position; but from 1880 to 1890 the development of the Lake Superior deposits and the establishment of cheap transportation made the United States practically independent of foreign ore, while the exploitation of the Mesabi range in 1893 transferred the command of the steel market to a point west of the Allegheny Mountains.

From 1883 to 1887 the production of Bessemer steel was 1,900,000 tons per year, being 89 per cent. of the total, the open-hearth

TABLE XXII-C.

Production per Year during Certain Periods of Bessemer and Open-Hearth Ingots and Rail Steel.

NOTE.—It is assumed that 100 tons of ingots = 83.3 tons of rails.

Period.	United States.				Great Britain.			
	Total steel.	Bessemer ingots.	Open-hearth ingots.	Bessemer rails plus 20 per cent. = rail ingots.	Total steel.	Bessemer ingots.	Open-hearth ingots.	Bessemer rails plus 20 per cent. = rail ingots.
1867–1871 incl...	44,000	20,000	800	19,000	.....	180,000	.....	.....
1872–1874 " ...	186,000	143,000	4,000	131,000	.....	482,000	.....	.....
1875–1879 " ...	632,000	558,000	26,000	508,000	963,000	742,000	141,000	*564,000
1880–1882 " ...	1,524,000	1,320,000	125,000	1,330,000	1,808,000	1,387,000	342,000	1,156,000
1883–1887 " ...	2,167,000	1,910,000	182,000	1,627,000	2,280,000	1,563,000	638,000	1,042,000
1888–1890 " ...	3,521,000	3,040,000	401,000	1,906,000	3,585,000	2,063,000	1,429,000	1,172,000
1891–1893 " ...	4,284,000	3,540,000	663,000	1,584,000	3,109,000	1,545,000	1,463,000	712,000
1894–1896 " ...	5,269,000	4,130,000	1,074,000	1,373,000	3,611,000	1,629,000	1,883,000	808,000
1897–1899 " ...	8,910,000	6,560,000	2,262,000	2,357,000	4,751,000	1,823,000	2,813,000	1,004,000
1900.....	10,188,000	6,685,000	3,398,000	2,861,000	5,050,000	1,745,000	3,156,000	912,000
1901.....	13,474,000	8,713,000	4,656,000	3,445,000	4,904,000	1,606,253	3,297,791	878,000
1902.....	14,947,250	9,138,363	5,687,729	3,522,470	4,909,067	1,825,779	3,083,288	1,083,859
1903.....	14,534,978	8,592,829	5,829,911	3,536,107	5,034,101	1,910,018	3,124,083	1,273,729
1904.....	13,859,887	7,859,140	5,908,166	2,565,548	5,126,879	1,718,538	3,245,346	999,649

*1875 is estimated.

TABLE XXII-D.

Proportion of Various Kinds of Steel made in the United States and Great Britain.

Period.	Bessemer steel.				Open hearth.	
	Per cent. of total.		Rail steel per cent. of Bessemer.		Per cent. of total.	
	United States.	Great Britain.	United States.	Great Britain.	United States.	Great Britain.
1867–1871 inclusive.....	45	.....	95	.....	2	.....
1872–1874 "	77	.....	92	.....	2	.....
1875–1879 "	88	77	91	76	4	15
1880–1882 "	87	77	100	86	8	19
1883–1887 "	89	70	85	67	9	28
1888–1890 "	87	58	63	57	11	40
1891–1893 "	83	50	45	46	15	47
1894–1896 "	78	45	33	50	20	52
1897–1899 "	74	38	36	55	25	59
1900.....	66	35	44	52	33	62
1901.....	65	33	40	55	35	67
1902.....	61	37	39	59	38	63
1903.....	59	38	41	67	40	62
1904.....	57	33	38	58	43	63

furnaces making one-tenth as much. Only 85 per cent. of the Bessemer steel was rolled into rails, for at Steelton, Cambria, Bethlehem and elsewhere, considerable high-carbon steel was being made, as well as some soft steel. Some Bessemer plants not connected with rail mills were operated to make steels for special purposes and supply the general trade, and this development became more pronounced from 1888 to 1890, when only 63 per cent. was put into rails, while from 1891 to 1893 more than half the Bessemer output went into miscellaneous work, and from 1894 to 1896 only one-third was used for rails.

This great change was brought about by many causes, among which was the general use of the reversing mill for rolling four-inch square billets directly from the ingot, and the immediate acceptance by the trade of that size as the standard. By the economies following this innovation wrought-iron was driven from the market and was superseded by steel. One of the most important fields affected by this change was the making of railway joints or splices, which amount to from five to seven per cent. of the weight of the rails themselves. A still greater change was the rapid and almost complete substitution of steel for plates and sheets of all kinds.

During all these years the open-hearth process has been making very heavy strides and narrowing the field of the Bessemer converter. One of the first acts of trespass was in high-carbon steels; it was found that the steel made in the regenerative furnace gave better results, and today very little high steel is made by the pneumatic method. The next encroachment was in structural shapes, where the Bessemer product found a great outlet in the years from 1885 to 1893. The converter product going into bridges is very small at present, while it is becoming less for ships and buildings. This growth of the open-hearth furnace is shown by the fact that in 1901 the steel made in the converter formed only 65 per cent. of the total output, while from 1875 to 1890 it was about 88 per cent. It is also shown by the fact that in the two years of 1900 and 1901 the proportion of Bessemer steel used for rails increased to an average of 42 per cent., it being only 33 per cent. in 1894 to 1896.

Today two-thirds of the steel made in the United States is Bessemer and one-third open-hearth. Practically all the rails are Bessemer, but open-hearth steel is used for almost all other work where the material is subject to physical and chemical specifications. One-

quarter of this open-hearth steel is made on an acid hearth, the remainder on dolomite or magnesite linings. The use of the basic furnace is spreading both in small and large plants, but few new Bessemer plants are being erected. No fuel is imported for the making of iron and steel, but a considerable quantity of ore is brought from Cuba to points on the Atlantic seaboard, as shown by Table XXII-E.

TABLE XXII-E.

Iron Ore Imported into the United States.

Imported from	1896	1898	1900	1903
Cuba	390,551	165,623	431,265	613,585
Spain	121,132	13,335	253,694	94,720
French Africa	79,661	.....	20,000	7,830
Italy	29,882	.....	18,951	.....
Greece	33,750	7,200	23,350	86,730
Newfoundland and Labrador	20,800	.....	140,535	6,843
United Kingdom	8,528	683	397	.....
Colombia	3,150	.....	3,000	169,681
Quebec, Ontario, etc	.....	.....	5,588	1,051
Other countries	5,352	367	1,051	.....
Total	692,806	187,208	897,831	980,440

A map is given in Fig. XXII-A, taken from the U. S. Geological Survey. This shows the coal fields of the United States, the anthracite deposits of eastern Pennsylvania being noted by solid black. The crosses denote important producers of ore, the only ones worthy of note being the Lake Superior deposits, and those of Alabama, Colorado and Cornwall, Pa. The circles indicate the steel-producing centers.

SEC. XXIIb.—*Coal:*

Anthracite.—Many years ago lump anthracite was commonly used in eastern Pennsylvania and New Jersey as the only fuel put into the blast furnace, but this practice has become the exception, and coke from Connellsville has for a long period been carried to furnaces situated in the heart of the hard coal region. Some furnaces do use anthracite alone, and at many plants it is not unusual to use a certain proportion of hard coal, but this hardly warrants the classification of many Eastern plants as "anthracite furnaces."

Hard coal is used in firing boilers, but only the small sizes are available, the larger kinds commanding a higher price for household use. Except in the neighborhood of the mines it is more economical

to use bituminous coal than the sizes that can be sold for domestic purposes. The smaller grades will not burn readily and require a blast when used under boilers. In many Eastern cities the com-

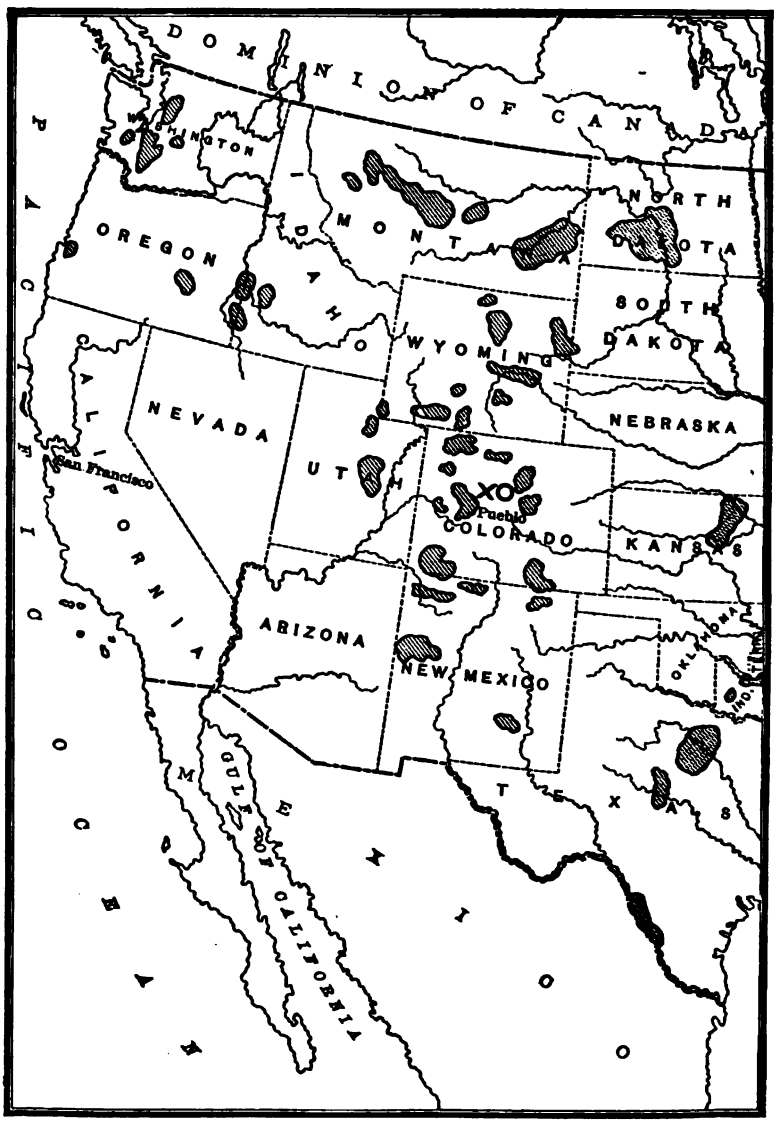


FIG. XXII-A.—UNITED STATES; WESTERN HALF.

munity demands a smokeless stack, so that factories are practically compelled to use hard coal; but aside from this, hard coal may be considered simply as the fuel for household purposes in the north-

FIG. XXII-A.—UNITED STATES; EASTERN HALF.

eastern part of the country. A certain amount is also raised in Colorado and New Mexico, but the quantity is trifling compared with the output of the Appalachian field. The hard coal district of Pennsylvania is divided into three parts, which are shown in Fig. XXII-B as Nos. 14, 15 and 16. Following is a description of each division:

No. in Fig. XXII B.	Name.	Local Districts.	Situation in Counties of Pennsylvania.
14	Wyoming.	Carbondale, Scranton, Pittston, Wilkesbarre, Plymouth, Kingston.	Luzerne and Lackawanna.
15	Lehigh.	Green Mountain, Black Creek, Hazleton, Beaver Meadow	Luzerne and small parts of Carbon, Schuylkill and Columbia.
16	Schuylkill	Panther Creek, Lorberry, East Schuylkill, West Schuylkill, Lykens Valley, Shamokin, East Mahanoy, West Mahanoy.	Carbon, Dauphin, Schuylkill, Columbia and Northumberland.

All this region is in the eastern center of the State. The total production of anthracite in 1903 was as follows, in short tons:

Pennsylvania	74,607,068
Colorado and New Mexico	72,731
Total	74,679,799

Bituminous.—In the production of anthracite coal eastern Pennsylvania stands alone, while in bituminous coal western Pennsylvania stands pre-eminently first. The leading counties are Westmoreland, Fayette and Allegheny, with Cambria, Clearfield, Jefferson and Washington following with heavy outputs. The Clearfield coal is one of the best coals for steam purposes, and, together with the Pocahontas and New River coals of West Virginia, is carried in great quantities to Eastern points. The Westmoreland coal is exceptionally rich, and is well adapted for making producer-gas.

The coal deposits of the United States are divided into seven fields, shown in Fig. XXII-A, but only four are important:

(1) The Appalachian, extending from New York to Alabama, a length of 900 miles, and a width varying from 30 to 180 miles.

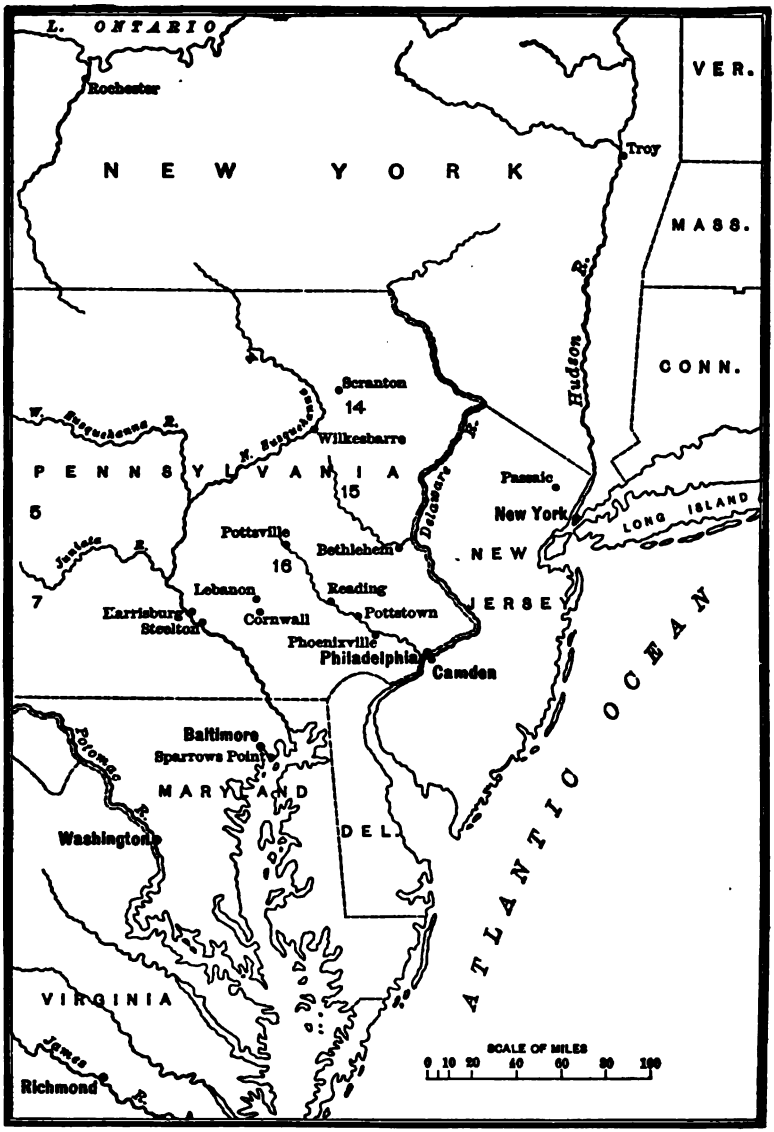


FIG. XXII-B.—PENNSYLVANIA, WEST VIRGINIA, OHIO, ETC.; EASTERN HALF.

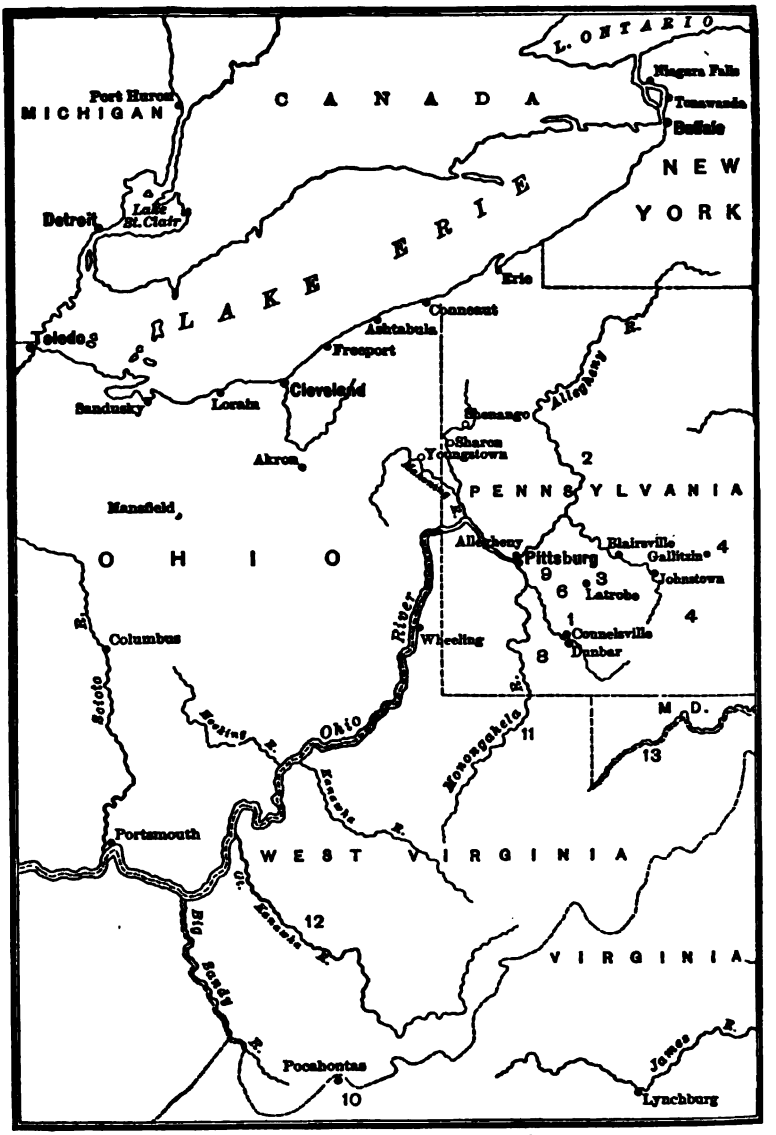


FIG. XXII-B.—PENNSYLVANIA, WEST VIRGINIA, OHIO, ETC.; WESTERN HALF.

(2) The Central, including Indiana, Illinois and Western Kentucky.

(3) The Western, including the coal west of the Mississippi River, east of the Rocky Mountains and south of the forty-third parallel.

(4) The Rocky Mountain, including the basins in that range.

The coal from the Central and Western divisions need not be considered here, as it has little bearing on the iron industry; the beds of the Appalachian and Rocky Mountain districts supply practically all the coal and coke used in this branch of metallurgy. Table XXII-F shows the output of coal and coke in the United States in 1902 by States, and Table XXII-G the output of the different fields. Table XXII-H gives the records for each county in Pennsylvania, and Table XXII-I the coke production in Pennsylvania and West Virginia. The division into fields is in accordance with the usage of the Geological Survey. The numbers refer to Fig. XXII-B.

TABLE XXII-F.

Output of Coal and Coke in the United States in 1902.

	Coal.		Coke.	
	Anthracite.	Bituminous.	No. of ovens.	Production.
Pennsylvania	41,373,595	94,525,584	36,609	16,497,910
Illinois*	.....	32,716,677	149	.....
Indiana*	.....	8,313,880	50	.....
West Virginia	.....	18,440,226	12,656	2,516,505
Ohio	.....	23,498,857	449	146,099
Alabama	.....	10,354,570	7,571	2,552,246
Colorado	52,611	6,073,962	3,010	1,003,393
Utah	.....	1,573,453	404	
Iowa	.....	5,871,766	.....	.....
Kentucky	.....	6,692,863	485	126,879
Kansas	.....	5,253,885	97	20,902
Wyoming*	.....	1,448,634	74	.....
Maryland	.....	3,872,523	.....	.....
Tennessee	.....	4,382,968	2,269	560,006
Virginia	.....	2,498,283	2,974	1,124,573
Massachusetts*	.....	.....	400	.....
Georgia	.....	414,083	492	82,064
Montana	.....	1,550,876	410	53,463
Indian Territory	.....	2,232,042	280	49,441
Others*	41,326	8,992,499	660	668,250
Total	41,467,532	238,697,631	69,069	25,401,730

*The coke production of Illinois, Indiana, Massachusetts, Michigan, New York Wisconsin, and Wyoming amounts to 2,063,894 tons, and is included under "others.' The separate statistics are not given in the Government report.

TABLE XXII-G.

Output of the Principal Coal Fields of the United States in 1902.

Field.	Product; tons.	Per cent. of total.
Appalachian	173,274,861	66.6
Central	46,133,024	17.7
Western	20,727,495	8.0
Rocky Mountains	16,149,545	6.2
Pacific Coast	2,834,058	1.1
Northern	964,718	0.4
Total	260,083,701	100.0

TABLE XXII-H.

Output of Bituminous Coal in Pennsylvania in 1902 and the Amount Used for Making Coke.

County.	Total coal mined; tons.	Amount coked; tons.
Fayette	19,613,161	11,768,503
Westmoreland	19,127,904	6,730,373
Allegheny	12,689,225	.....
Cambria	10,942,496	946,183
Washington	9,216,267	3,934
Clearfield	7,462,682	291,838
Jefferson	6,474,764	1,314,165
Somerset	5,957,751	74,216
Indiana	2,043,140	194,021
Armstrong	1,920,584	.....
Others	7,069,204	371,075
Total	103,117,178	21,694,308

Pennsylvania Coke Districts.

No. 1.—Connellsville: The County of Fayette and the southern half of Westmoreland.

Pittsburgh: Vicinity of Pittsburgh, the coke being made from coal brought down the Monongahela River.

No. 2.—Reynolds and Walton: Ovens on the Rochester and Pittsburgh Railroad, the Low Grade Division of the Allegheny Valley Railway, and the New York, Lake Erie and Western Railway.

No. 3.—Upper Connellsville: Around and north of Latrobe, the coal being different from the deposit farther south.

No. 4.—Allegheny Mountain: Ovens along the Pennsylvania Railroad from Gallitzin to beyond Altoona, and those in Somerset County. Also those near Johnstown.

No. 5.—Clearfield Center: Clearfield and Center counties.

TABLE XXII-I.

Coke Statistics for Pennsylvania and West Virginia for 1903.

State and District.	Coke ovens.		Production; tons.
	Built.	Building.	
Pennsylvania—			
Connellsville	22824	330	9099100
Lower Connellsville	5595	586	2332589
Pittsburgh	1636	359	877640
Reynoldsville (Walton)	2003	....	810359
Upper Connellsville	2506	280	784133
Allegheny Mountain	2047	100	739263
Greensburg	1332	....	451385
Broadtop	571	....	244898
Clearfield Center	650	....	166355
Irwin	691	....	133290
Others	237	130	.....
Total	40092	1785	15639011
West Virginia—			
Flat Top (Pocahontas)	8994	1329	1314758
Upper Monongahela	2319	337	437522
Upper Potomac	1090	200	406706
New River	2243	500	368844
Kanawha	967	321	179988
Total	15613	2687	2707818

No. 6.—Greensburg: The central part of Westmoreland County.

No. 7.—Broad Top: The Broad Top coal field in Bedford and Huntingdon counties.

No. 8.—Lower Connellsville: A new district, known also as the Klondike district; a southwest extension of the Connellsville Basin.

No. 9.—Irwin: The neighborhood of Irwin on the Youghiogheny River, in the western part of Westmoreland County.

West Virginia Coke Districts.

No. 10.—Pocahontas: The counties of McDowell and Mercer in West Virginia and Tazewell County in Virginia. Most of the output comes from the West Virginia side. This district is traversed by the Norfolk and Western Railroad.

No. 11.—Upper Monongahela: Also called the Fairmount district; it is the northern part of the State, drained by the Monongahela, and shipping its coal by the Baltimore and Ohio Railroad. It embraces Preston, Taylor, Harrison and Marion counties. The statistics include the ovens located at Wheeling, at the Riverside Iron Works.

No. 12.—New River and Kanawha: Named from the rivers draining them, and embracing Fayette and Kanawha counties. The coal is shipped partly by the Chesapeake and Ohio Railroad and partly by the Kanawha River.

No. 13.—Upper Potomac: Also called the Elk Garden district; includes Mineral, Tucker and Randolph counties and is the southern extension of the Cumberland district of Maryland. The West Virginia Central and Pittsburgh Railway runs through this field.

SEC. XXIIc.—*Lake Superior:*

NOTE: I am indebted to A. I. Findley, formerly Editor of *The Iron Trade Review*, for much information that is here printed for the first time.

Up to 1880 the State of Pennsylvania was the heaviest producer of iron ore in the Union, but the amount raised was entirely insufficient to supply its blast furnaces, and large quantities were imported from Spain, and from the west coast of England. For years Michigan had been mining ore, the Marquette deposits having been opened in 1845, but it was not until 1856 that as much as 5000 tons was shipped to Pennsylvania. Transportation was high and Spanish ores were taken to Pittsburgh as cheaply as the Western ores could be laid down at that point. The Menominee beds were opened in 1877, the first shipments from Escanaba being made in 1880, and in about the year 1881 the output of Michigan exceeded that of any other State. In 1884 the Gogebic range was opened, all three districts being in northwest Michigan, but in the same year the Vermilion mines in northeastern Minnesota began to produce, and when, in 1892 and 1893, the Mesabi range was exploited, Minnesota became a dangerous rival. In 1901 the Mesabi mines produced 9,303,541 tons and the Vermilion 1,805,996 tons, a total of 11,109,537 tons, while Michigan raised only 9,654,067 tons, thus giving first rank to Minnesota. In 1903 the Mesabi and Vermilion districts together produced 33 per cent. more than the three ranges of Michigan.

The cause of this increase is not simply the opening of new mines, for this is but one factor in the work, the other factor being the great decrease in cost of transportation. These two conditions are interdependent, since the lessening in the cost of freight could not have come about without the transport of enormous tonnages. In no other part of the world has there been such a complete system of handling material worked out on such a gigantic scale; the steam shovels in the mines, the railroads to the ports, the mammoth docks and arrangements for loading vessels in a few hours, the special fleet of ore carriers; the improvement of the locks, the unloading machinery at lower lake ports, and the storage yards and handling apparatus at the Eastern furnaces, each one of these is a link in a chain of specialized machinery, by which it has become possible to transport ore a thousand miles and make pig-iron for less than half a cent a pound.

Table XXII-J shows the production of the different ranges in 1903, and gives figures for comparison with the other large producers. The States of Michigan, Wisconsin and Minnesota, constituting the Lake Superior region, raised 26,573,000 tons of ore.

TABLE XXII-J.

American Ore Supply in 1903.

Lake Superior Ranges.	Location.	Date when opened.	Output; tons.	Fe. dried at 212°F	P.	S.	SiO_2.	$CaCO_3$.	H_2O.
Mesabi	N. E. Minn.	1892	13,452,812	61–64	.03–.08	.01	3–5	0.5	8–12
Menominee	N. W. Mich.	1877	4,093,320	56–62	.01–.75	.01	3–6	1.0	5–10
Marquette	N. W. Mich.	1855	3,686 214	60–67	.02–.15	.02	2–6	0.5	1–12
Gogebic	N. W. Mich.	1884	3,422,341	58–62	.04–.08	.01	3–7	0.3	10–12
Vermilion	N. E. Minn.	1884	1,918.584	61–67	.04–.15	tr.	3–5	0.4	1–6
Total			26,573,271						

Other States.		Other States.	
Alabama	3,684,960	New Jersey	484,796
Tennessee	852,704	Georgia	443,452
Virginia and West Virginia	801,161	Other States	1,922,150
Pennsylvania	644,599		
New York	540,460	Total	35,019,306

The only competitor is the Minette district of Germany, France, Belgium and Luxemburg, which mined 22,000,000 tons in the same year.

The Marquette ores are magnetites and hard and soft hematites, and are rich in iron. The ores from the Menominee and Gogebic ranges in Michigan and Wisconsin are hematites, and are very desirable as being in porous lumps and easily smelted. The Vermilion ores are very rich hematites; the softer kinds are low in phosphorus, while the deposits that furnish the massive hard lumps generally run considerably above the Bessemer limit. The Mesabi beds, for the most part, are mined with a steam shovel, as large areas lie near the surface. It is economical, however, to first loosen the ground by explosives. The ores are usually very fine, like sand, and in some cases almost pulverulent. Different mines vary in character, some ore being of such a size that it can be used alone in a blast furnace, while other beds are so fine and dusty that the average furnace manager will not use over 20 per cent. The composition of the ore, not only in the Mesabi districts but elsewhere, varies considerably, and constant vigilance is necessary to insure the separation of the "Bessemer" from the "non-Bessemer," by which terms are meant those portions which will give a pig-iron running below 0.10 per cent. in phosphorus, and those which will give an iron above that limit. The non-Bessemer was formerly more or less of a drug in the market, but the development of the basic open-hearth furnace has furnished an outlet for this off-grade iron.

The fine condition of many Mesabi ores prevents their being employed alone in the blast furnace, and it is usually necessary to mix with them a certain proportion of the "old range" ores. This renders it possible for the old mines to sell their product at a higher price, and thereby cover their greater cost. The percentage of Mesabi ores used in the furnace mixture is higher than formerly, from two causes: first, that furnacemen are learning how to use them, and are becoming accustomed to slips and scaffolds; and second, that many mines recently opened give a product of much coarser nature. The effect is seen in a relatively increasing price for these ores. The "Mesabi differential" for Bessemer ores was only 25 cents in 1905, while it was $1.10 in 1902. On non-Bessemer ores it was 20 cents in 1905, against 63 cents in 1902.

In regard to the relative amounts of the two kinds of ores I quote D. E. Woodbridge, in *The Iron Age,* January 3, 1901:

"The fancy Bessemer ores of the older ranges, excepting the

Gogebic and new Vermilion fields, are practically gone. On the Mesaba the greatest share of desirable Bessemers is included in one township. The Menominee range has little Bessemer ore, nearly all coming from the Aragon, Loretto and Pewabic mines. On the

TABLE XXII-K.

Lake Superior Mines which Produced over 200,000 Tons in 1904, and which, up to Jan. 1, 1905, have Produced over 1,000,000 Tons.

Those marked thus * are owned by the United States Steel Corporation.

Range and Name of Mine.	Production in 1904.	Total Output up to Jan. 1, 1905.	Composition dried at 212° F. per cent.								Natural State.	
			Fe.	P.	SiO_2	Mn.	Mn_2O_3	CaO.	MgO.	S.	Loss at 212° F.	Loss on Ignition.
Marquette Range	743,263	13,123,224	62.4	.109	4.18	0.22	2.2	1.4	1.0	.021	1.3	2.7
Cleveland Cliffs	262,486	6,858,080										
L. Angeline	590,389	12,313,058										
*L. Superior	311,479	4,778,785	61.4	.150	5.56	0.29	2.6	0.5	0.5	.010	12.9	
*Queen												
Mesabi Range	940,105	6,475,017										
*Adams	647,614	5,507,856	63.7	.039	2.54	0.48	0.9	0.2	0.1	.008	7.9	12.0
Biwabik	256,573	1,170,801										
Clark	975,102	9,940,727										
*Fayal	244,150	2,416,128										
*Genoa	1,415,894	4,962,469	63.4	.038	3.30	0.53	1.3	0.2	0.1	.006	9.8	12.6
*L. Sup. Group	706,225	6,507,422	63.8	.046	2.72	0.52	1.9	0.2	0.1	.016	10.5	13.3
Mahoning	1,168,855	9,771,770	64.0	.042	3.98	0.20	1.8				12.3	
*Mountain Iron	297,960	1,232,548										
Sellers	589,319	2,100,865										
Spruce	1,852,021	4,829,588	64.6	.039	3.25	0.32	0.9	0.2	0.2	.005	8.2	10.5
Stevenson												
Menominee Range	374,944	4,066,607	63.2	.036	4.39	0.14	1.0	0.9	1.8	.007	6.5	
*Aragon	541,324	12,501,788	58.1	.165	6.50	0.54	1.4	1.2	3.6	.019	7.0	
*Chapin	572,791	4,601,806	64.6	.010	4.15	0.14	0.9	0.6	1.3	.008	8.5	9.5
*Pewabic												
Vermilion Range	422,162	8,556,326	64.4	.040	4.20	0.22	2.2	0.6	0.1	.002	5.5	
*Chandler	500,432	3,785,330	64.3	.039	4.46						4.6	
*Pioneer												
Gogebic Range	344,102	3,818,905	60.7	.043	7.02	0.26	2.7	0.3	0.2	.010	10.9	13.1
Ashland	212,910	3,961,683	62.4	.096	4.84						11.0	
*Aurora	618,638	12,112,151	63.2	.038	4.03						10.8	
*Norrie	204,581	4,152,648	63.4	.048	3.22	0.76					12.2	
*Tilden	14,308,749	149,534,382										
Total for L. Superior	21,622,889	285,666,359										

Marquette the once famous Lake Angeline mines are fast nearing the end of their fine Bessemer ores, and there remains but a few years more of their production. All the mines of the Oliver Company on that range are now classed as non-Bessemer, and the Cleveland Cliffs are light in their Bessemer production. The ore bodies under Lake Angeline are not furnishing the percentage of high-grade ores expected. Explorations on the range are showing few Bessemer deposits. On the Gogebic one company controls four-fifths of the deposits, and a large share of the rest is off the market. Explorations around the old Comet and Puritan, Federal and Jackpot group are said to be producing good results, and there are hopes of some tonnage in that section. On the Vermilion the hard ore property at Tower is now a producer of non-Bessemer ores exclusively. The Chandler in a few years will be exhausted. The new mines of the Oliver Company are large properties, but have no effect on the general situation, as the owners will retain their ores for their own use. On the Mesaba low-grade non-Bessemers are much in excess of its fancy ores. There are large deposits of lean ores and of ores high in phosphorus, or of ores so fine and dusty that they are discriminated against; but of high-grade desirable Bessemers the discoveries can be counted quickly. It would appear that the larger deposits of the range have been found."

Table XXII-K gives a list of the important mines in the Lake region. The division is arbitrary, embracing only those mines which have produced over one million tons in their lifetime and which turned out over 200,000 tons during 1904. This classification omits a few new mines which produced more than 200,000 tons in 1904, and which may take first rank in the future, but which had not then turned out one million tons.

The output of the mines in this list amounted to fourteen million tons in 1904, or two-thirds of the total for the year. During the lifetime of the Lake Superior field these mines have produced 56 per cent. of the total, so that the chemical composition of these ores may be taken as representative of the district as a whole. In addition to this list there are several mines which have exceeded the limit of one million tons, but which are shipping less than two hundred thousand tons per year. In this class are the following, the properties of the United States Steel Corporation being marked with a star:

Marquette.—Cambria, Champion, Jackson, Lillie, *Negaunee, Republic, Clark, *Volunteer, *Winthrop.

Mesabi.—*Auburn, Franklin, Sparta, Sellers, Spruce.

Menominee.—Commonwealth, Crystal Falls, Florence, Hemlock, Penn Iron.

Gogebic.—Brotherton, Cary, Colby, Iron Belt, Montreal, Newport, Palms.

There are other mines which have produced over one million tons in the past, but which have shipped very little or no ore in recent years. Following is a list of these:

Marquette.—New York (York).

Mesabi—*Oliver (Mesabi Mountain and Lone Jack).

Menominee.—Dunn, Ludington.

The mines of the United States Steel Corporation have been withdrawn from the general market. This has raised the cost of ore to outside companies, a result viewed with complacency by the dominant interest.

TABLE XXII-L.

Price of Lake Superior Ore at Lower Lake Ports.

	Old Range Ore.						Mesabi Ore.					
	Bessemer. P=.045			Non Bessemer.			Bessemer. P=.045			Non Bessemer.		
Year.	Price per ton.	Fe guarantee.	Price per unit; cents.	Price per ton.	Fe guarantee.	Price per unit; cents.	Price per ton.	Fe guarantee.	Price per unit; cents.	Price per ton.	Fe guarantee.	Price per unit; cents.
1898..	2.75	56.70	4.89	1.90	54.56	3.48	2.00	56.70	3.53	1.70	56.00	3.04
1899..	2.95	56.70	5.20	2.00	54.56	3.67	2.15	56.70	3.79	1.90	56.00	3.39
1900..	5.50	56.70	9.70	4.15	54.56	7.61	4.65	56.70	8.20	3.75	56.00	6.70
1901..	4.25	56.70	7.50	3.00	54.56	5.50	2.70	55.70	4.76	2.40	56.00	4.29
1902..	4.25	56.70	7.50	3.25	52.80	6.16	3.15	56.70	5.56	2.62	52.80	4.96
1903..	4.50	56.70	7.94	3.60	52.80	6.82	4.00*	56.70	7.05	3.20*	52.80	6.06
1904..	3.75	56.70	5.73	2.75	52.80	5.21	3.00*	56.70	5.29	2.65*	52.80	5.00
1905..	3.75	56.70	6.61	3.20	52.80	6.06	3.50*	56.70	6.17	3.00*	53.00	5.66

* The price of Mesabi ores varies not only according to the composition but according to the amount of fines, this being determined by sieves.

In Table XXII-L are given the prices of ore delivered at lower lake ports. It will be seen that in 1900 there was a decided advance, with a strong reaction during the next year. Since then the effect of the great industrial combinations and of the general activity in the iron trade has increased the price so that in 1903 the cost of ore in the open market was nearly double what it was in 1898. The almost unlimited demand, even in face of rising prices and the ex-

pectation of a virtual monopoly of existing supplies by the direct control of steel companies, has resulted in extensive prospecting and in the establishment of very high prices for ore lands. In many cases silicious ores have been purchased which would not have been considered at all a few years ago. In some cases these silicious ores are used in admixture with purer ores, both of the old ranges and of the Mesabi district. A very moderate output of highly silicious ores, however, will satisfy demands of this character, and the cost of transportation and of extra fuel will work against the use of these impure deposits. Attempts have been made to develop extensive deposits of titaniferous ores, but such mineral cannot be regarded as marketable, owing to the difficulty in smelting.

In other parts of the world iron ore is sold at a certain price per ton, and the purchaser runs the risk of variations in the composition. In Lake Superior products a sliding scale is used, the selling price depending on the iron and phosphorus. Following is the clause as written into all ore contracts:

"The price of this ore is named and accepted on the expectation that the ore will average ..... per cent. in metallic iron and ..... one-thousandths of one per cent. in phosphorus, dried at 212° F. Taking this as a standard of quality, it is agreed that only a total average variation therefrom of more than one-half of one per cent. in metallic iron (and in such case the entire average variation) shall be entitled to recognition and adjustment by increase or abatement in price, as the case may be, at the rate of ..... cents per unit per ton for metallic iron. And in case of excess of phosphorus over and above the agreed quantity, settlement shall be made according to the table of phosphorus values attached hereto."

The phosphorus table is different in Bessemer and non-Bessemer ores. In Bessemer ores the base is .045 per cent. For a lower content a higher price is paid, and for a higher content a lower price. The scale is as follows, the figures representing the difference in cents on one ton of ore:

.045=base.	.040=4½ cents more.
.050=4½ cents less.	.035=10¼ cents more.
.055=10¼ cents less.	.030=17¼ cents more.
.060=17¼ cents less.	.025=25½ cents more.
.065=25½ cents less.	.020=35 cents more.
.070=35 cents less.	

In some cases a lower base may be specified, while with non-Bessemer ores it is higher.

The freight rates on the lakes vary. A vessel may be chartered for a season or for a definite amount at a "contract rate," or the ore may be shipped on the best bargain that can be made at the moment—what is known as a "wild rate." In the long run the two come out about the same; thus in the ten years from 1890 to 1900 the average contract rate from the head of the lakes was 90½ cents per ton and the wild rate 90 cents. In 1887 the wild rates were $2.23 and the contract rates $2.00, but in 1900 the average charter was $1.25. These figures are for the full journey from the head of the lakes, Duluth or Two Harbors, the rate being lower for lesser distances; for instance, the average contract rate from Marquette for the last ten years has been 85 cents and for Escanaba 67½ cents. A certain amount is shipped all the way by rail, but this constitutes only 2 per cent. of the whole.

The ores of the Vermilion range are shipped from Two Harbors, the rail transportation being from 70 to 95 miles. The Mesabi deposits send their product by railroad to Duluth and Two Harbors, the distance being from 75 to 100 miles. The Menominee ores are all shipped from Escanaba and Gladstone, the distance hauled being from 40 to 92 miles. The Gogebic ores are mostly

TABLE XXII-M.

Movement of Lake Superior Ore.

	1897	1900	1904
Mesabi	4,280,873	7,809,535	12,156,008
Menominee	1,937,013	3,261,221	3,074,848
Marquette	2,715,085	3,457,522	2,843,706
Gogebic	2,258,236	2,875,295	2,308,287
Vermilion	1,278,481	1,655,820	1,232,513
Iron Ridge	.....	.....	67,480
Total	12,469,688	19,059,393	21,822,839
Duluth	2,876,064	3,888,926	4,649,611
Two Harbors	2,651,465	4,007,294	4,566,542
Escanaba	2,302,121	3,436,734	3,644,267
Superior	531,825	1,522,899	4,169,990
Ashland	2,067,637	2,633,687	2,288,400
Marquette	1,945,519	2,661,861	1,907,301
Gladstone	341,014	418,854	553
All Rail	253,993	489,078	596,175
Total	12,469,638	19,059,393	21,822,839

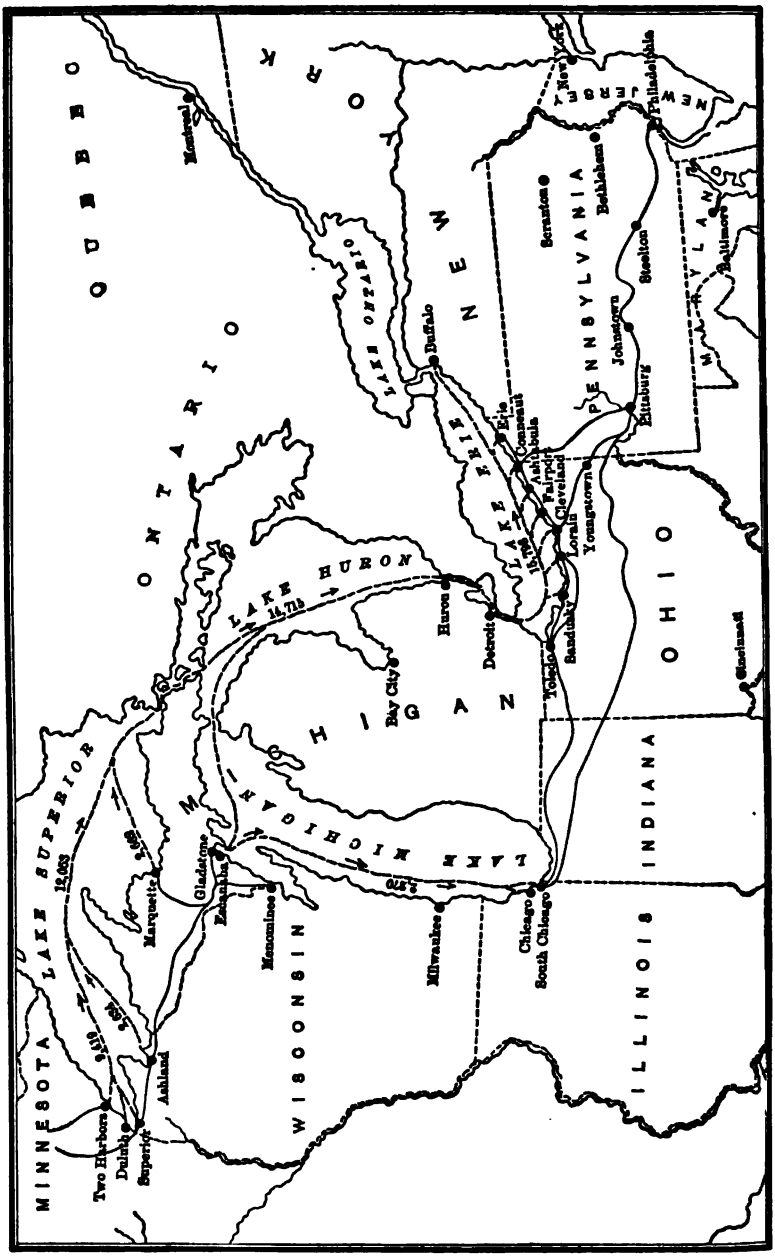


FIG. XXII-C.—MAP OF LAKE REGION.

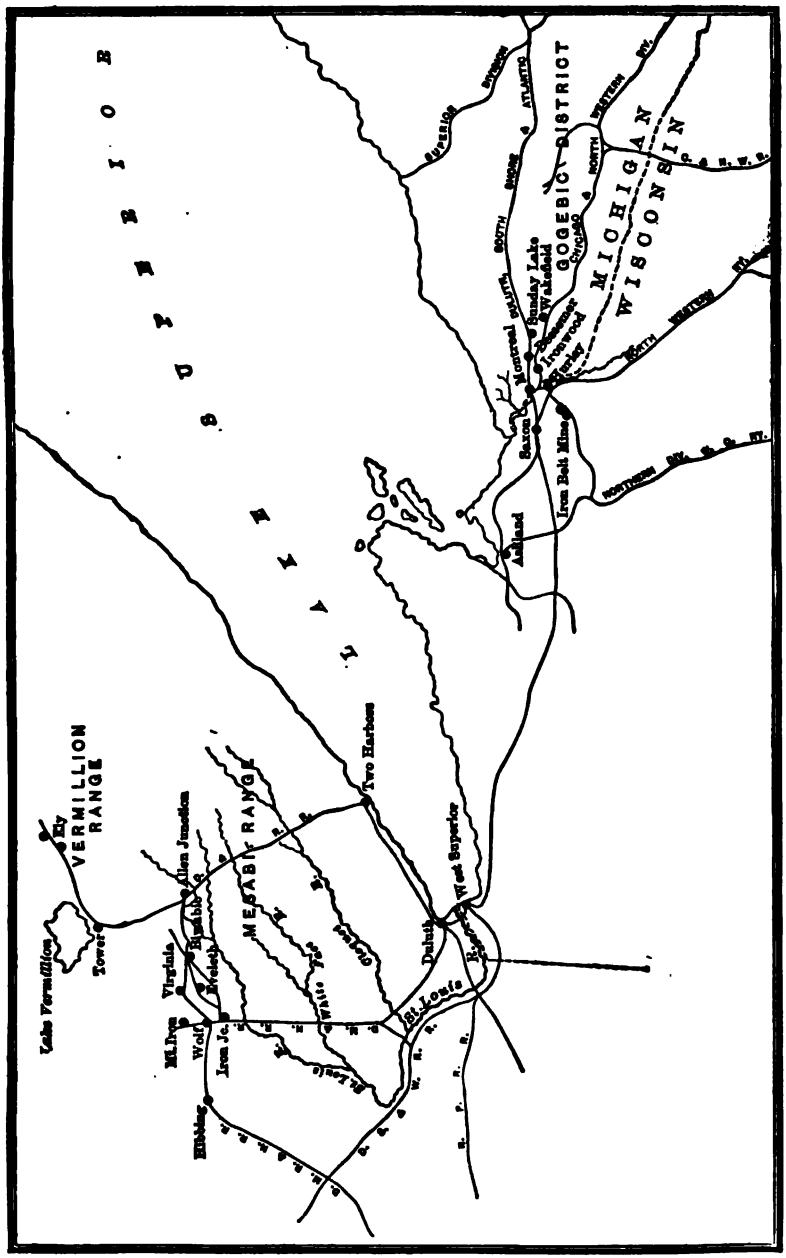


FIG. XXII-D.—MESABI, VERMILION AND GOGEBIC RANGES.

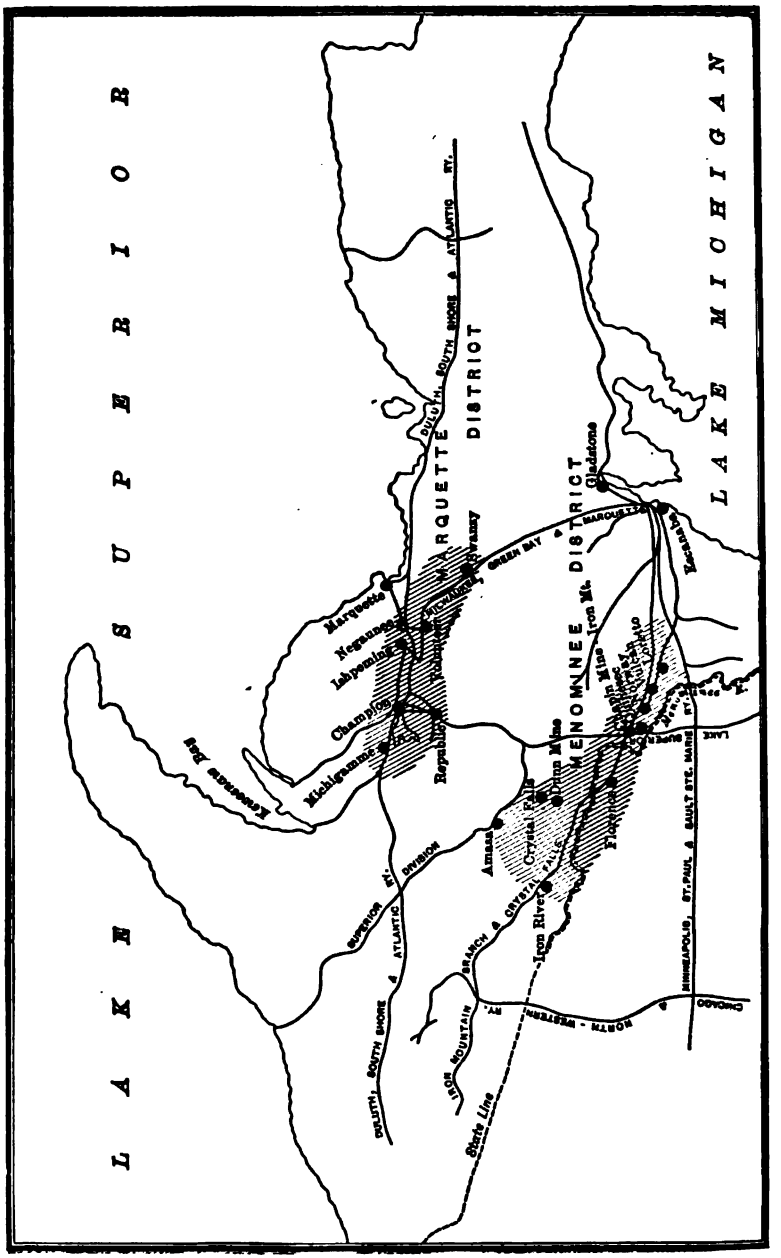


FIG. XXII-E.—MARQUETTE AND MENOMINEE RANGES.

shipped from Ashland, the distance being from 40 to 52 miles. The Marquette mines divide their shipments between Marquette and Escanaba, as it often pays to make a slightly longer land journey to save a great distance by water, and this is especially true of material going to Chicago.

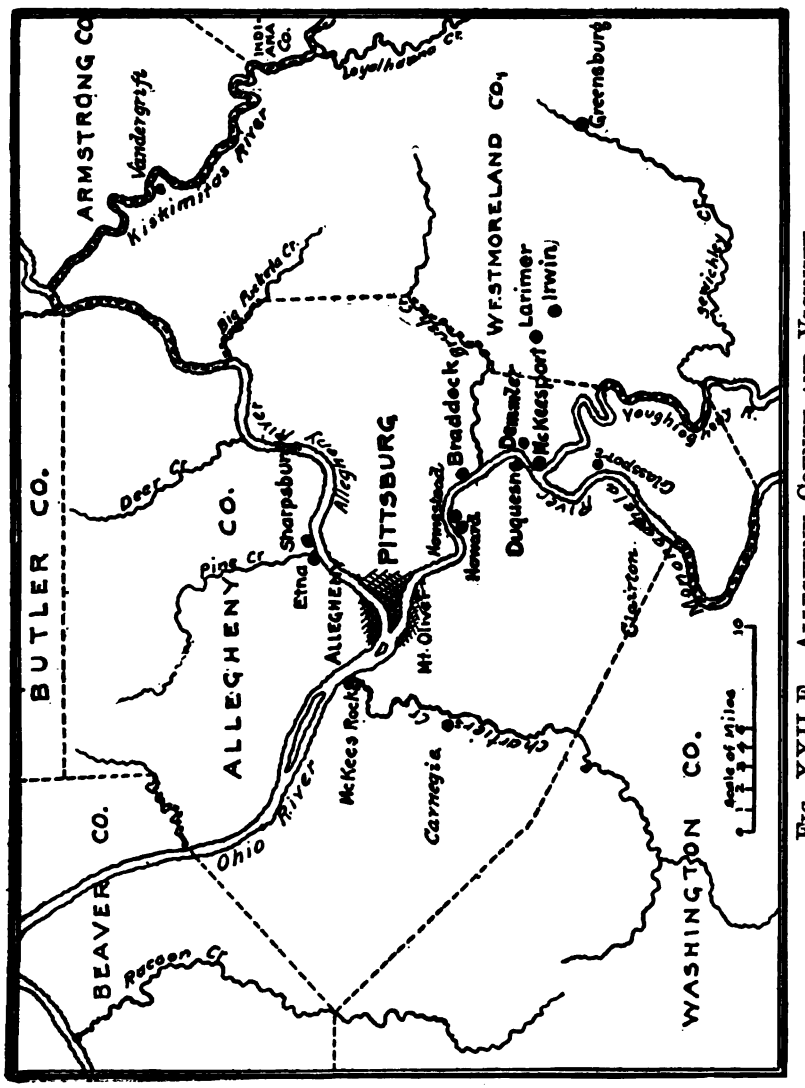


FIG. XXII-F.—ALLEGHENY COUNTY AND VICINITY.

The movement of ore during the last few years may be seen in Table XXII-M, while Fig. XXII-C shows the route followed to Chicago and the Lake Erie ports. The map in Fig. XXII-B gives more detail concerning the Eastern points to which the ore is carried, while Figs. XXII-D and XXII-E give views of the mining districts.

SEC. XXIId.—*Pittsburgh:*

The great center of the iron industry of the United States is around Pittsburgh in Allegheny County, Pennsylvania, a map of which is shown in Fig. XXII-F. This county produces one-quarter of all the iron made in the country and hence might be discussed separately. But from an economical standpoint we must embrace parts of three States:

Pennsylvania: Allegheny, Westmoreland and Fayette counties and the Shenango and Beaver valleys.

Ohio: The Mahoning Valley and Ohio River counties.

West Virginia: The northern point between Pennsylvania and Ohio, comprising Marshall and Ohio and Preston counties.

This gives a rectangle 70 miles north and south and 80 miles east and west. The statistics for each county of Pennsylvania are of record, but neither Ohio nor West Virginia collects such information; we do have the total production of pig-iron and steel in Ohio and the output of pig-iron in West Virginia, and the location and number of converters and open-hearth furnaces and their productive capacity for each works, while I am in possession of considerable private information as to the output of certain centers.

Output of Pig-Iron and Steel in the Pittsburgh District in 1901.

	Pig Iron.	Steel.
Allegheny County	3,685,665	5,138,839
Shenango Valley	979,415	484,692
Westmoreland, Fayette, etc.	115,261	158,525
Mahoning Valley	1,404,857	Est.
Southeastern Ohio	527,958	(1,540,000)
West Virginia	166,597	
Totals	6,879,753	7,317,056

The Shenango Valley, in Northwestern Pennsylvania, made over one million tons of pig-iron in 1903, but two-thirds was shipped to Pittsburgh for conversion. The Mahoning Valley makes half

TABLE XXII-N.

Production of Pig-Iron and Steel in Pennsylvania in 1903.

County.	Rolled Iron & Steel.		Steel Ingots.		Pig Iron.	
	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.
Allegheny	4,860,906	59.94	5,530,520	67.06	4,291,671	52.46
Cambria	568,282	7.01	804,633	9.76	611,328	7.47
Dauphin	466,951	5.76	439,662	5.33	337,587	4.13
Montgomery	332,366	4.10	197,111	2.39	276,649	3.38
Chester	322,585	3.98	372,475	4.52	.....	.....
Lawrence	309,198	3.81	360,369	4.37	457,979	5.60
Westmoreland	257,743	3.18	188,125	2.28	54,994	0.67
Berks	158,091	1.95	2,414	0.03	254,549	3.11
Mercer	131,895	1.63	65,939	0.80	595,147	7.27
Lehigh	86,543	1.07	.....	.....	386,872	4.73
Lebanon	85,043	1.05	.....	.....	133,351	1.63
Philadelphia	74,561	0.92	68,400	0.83	.....	.....
Northampton	51,974	0.64	107,523	1.30	213,274	2.61
Bedford	.....	.....	.....	.....	127,787	1.56
Others	402,998	4.96	110,207	1.33	441,464	5.39
Total	8,109,133	100.00	8,247,377	100.00	8,181,652	100.00

of all the pig-iron made in Ohio and over half of all the steel. Some pig-iron goes to Pittsburgh, while the furnaces of Southeastern Ohio ship considerable quantities to the steel plants of West Virginia. In any other part of the world districts like these would stand alone, but they are overshadowed by Allegheny County in Pennsylvania, which in 1903 produced 4,300,000 tons of pig-iron and 5,500,000 tons of steel. One-half of this steel is made in acid converters and half in basic open-hearth furnaces.

The foundation of this industry lies in the coal fields of the Connellsville district, in the counties of Westmoreland and Fayette in Pennsylvania, and the whole district including this section is approximately 80 miles square. Throughout this area the conditions are practically uniform, the ore supply coming by water from Lake Superior to some Lake Erie port, and thence by rail. The plants near the coal must haul the ore farther, while the plants near Lake Erie have a longer distance to bring the coke. In the case of finished products the difference in freight is trifling on shipments to distant points. It would be difficult to explain the reasons for locating each works at the particular place where it is built. In the immediate vicinity of Pittsburgh, about every piece of level ground is taken that lies along the river front. The country is very rugged and suitable sites for large steel works are not numer-

ous. In many parts of Europe works are built where water is scarce, but in America it is considered essential that a river be available, and this river is looked upon as small unless it is as large as the Rhine. Pittsburgh stands at the junction of two rivers, and both are bordered by high and steep hills, so that the iron and steel works extend in long, narrow lines along both banks of both rivers.

In about the year 1884, natural gas was discovered in the region around Pittsburgh, and during the next ten years this district enjoyed one of the best and most convenient fuels at very low rates. Many plants are using it to-day, but the cost is much higher than formerly and the supply uncertain, so that many plants in the city proper have been forced to install gas producers, but natural gas is still used at Homestead and Duquesne.

The advantages of this fuel are not confined to its first cost, as an open-hearth furnace using it is radically different from the usual type. The gas needs no regeneration and is introduced at the point where the port opens into the furnace, so that both chambers are used for air. There is no leak from one to the other; there are no ports to wear out, and when the furnace is repaired the brickwork may be laid in the most rapid manner, without any attention to making joints tight. The gas contains no sulphur, so that it is easy to make steel low in this element. It is not known how long the gas will last. New wells are constantly being sunk and the supply replenished from a greater distance, but the time seems near when the amount will be so scanty that it will be used for household purposes only.

It is around Pittsburgh that the methods have been developed in blast furnaces and rolling mills which have become known as "American practice," and I believe it is but the truth to state that these standards have in the main been established by the Carnegie Steel Company.* The policy of the Carnegie management for twenty years was diametrically opposed to the policy in European works, and quite different from what is possible in most cases. Most corporations must distribute their earnings in the way of dividends, and the most successful management is the one that distributes most; but where there are few stockholders and when

* The system of casting upon trucks, without which the great products in a Bessemer plant are difficult to obtain, as well as other features of Bessemer construction, were inaugurated at the works of the Maryland Steel Company, at Baltimore.

ine control rests in a man with a definite plan, that plan can be carried out, when in other works the plan might be conceived, but could not be accomplished.

The principle at Pittsburgh was to destroy anything from a steam engine to a steel works whenever a better piece of apparatus was to be had, no matter whether the engine or the works was new or old, and the definition of this word "better" was confined to the ability to get out a greater product. Such a course involved the expenditure of enormous sums of money, it involved the constant return of profits into the business, it involved mistakes, but it produced results, and the economies from the increased output soon paid for the expenditure.

There is, however, a lack of attention to minor economies. The saving of fuel does not receive its share of attention, and while thousands of dollars are spent to dispense with the labor of one or two men, thousands of dollars in fuel are wasted. In Europe the labor is wasted and the fuel saved. There is a partial excuse in both cases. In Europe fuel is costly and labor cheap; in Pittsburgh fuel is cheap and labor costly. When a mill is working to its ultimate capacity, it takes more than one man to fill one job, because continuous work is impossible. Consequently, extra hands must be provided that would be superfluous in foreign work. A machine that saves the work of "one man" really saves more than one man, and in Pittsburgh this will represent from five to ten or even twenty times as much as in Silesia or Lothringen. On the contrary, fuel is cheap in Western Pennsylvania, and it is better to waste money than to have complicated apparatus to get out of order.

This idea has led to a sameness in the methods of manufacture in America, rendered quite natural by the fact that the metallurgical conditions are uniform over a large area. Throughout the greater part of America, the use of Lake Superior ores is universal, these ores being of two kinds: (1) those that give a pig-iron with not over 0.10 per cent. of phosphorus; (2) those that give a pig-iron ranging from 0.10 to 0.25 in phosphorus. The last, the "non-Bessemer," is sold at a lower price, and while all of the Bessemer steel is made in acid converters, a great part of the open-hearth product is made on the basic hearth, the non-Bessemer pig-iron being used for this purpose. The low content of phosphorus takes away all

difficulties as far as this element is concerned, and the metallurgical problems are few; the coke is good, the ores rich and pure, the basic Bessemer process out of the question, and the basic open-hearth furnace is charged with a mixture almost fit for an acid hearth. It is therefore easier in America than in Europe to make steel to rigid specifications, this being proven by the fact that foreign metallurgists refuse to bid on contracts which are accepted as standard in America.

The Pittsburgh district mines no ore, all this coming from the Great Lakes. During a considerable portion of the year navigation is closed by ice, and as no ore arrives between the first of December and the next May, consequently, it is necessary to have an enormous storage yard. The coke arrives by rail, and very little is

TABLE XXII-O.

Plants in the Pittsburgh District having Bessemer Converters or at least Six Open-Hearth Furnaces.

Works.	Location.	Bessemer Converters and Capacity.	Open Hearth Furnaces and Capacity.	No. of Blast Furnaces.
Allegheny County, Pa.:				
*Duquesne	Cochran	2-10	12-50	4
*Edgar Thomson	Bessemer	4-15		9
*Homestead	Munhall	2-12	1-20 19-40 22-45	
*Monongahela	McKeesport	2-8		2
*Shoenberger	Pittsburgh	2-7	3-35	2
*Twenty-sixth Street	Pittsburgh	2-5		
*St. Clair	Clairton		8-50	3
American (Jones & Laughlin)	Pittsburgh	2-10	1-25 6-40	4
Carbon Steel Co.	Pittsburgh		8-50	
Black Diamond (Parks)	Pittsburgh		2-18 5-30 1-50	
Westmoreland County, Pa.:				
*Vandergrift	Vandergrift, Pa.		6-30	
Shenango Valley, Pa.:				
*New Castle	Newcastle	2-8		4
*Sharon Works	Sharon		6-30	2
*Sharon Steel Co.	Sharon		13-50	1
Mahoning Valley, Ohio:				
*Ohio	Youngstown	2-10		3
Brown, Bonnell	Youngstown	2-6		
Ohio River counties, Ohio:				
*Bellaire	Bellaire	2-10		2
*Mingo	Mingo Junction	2-10		3
West Virginia:				
*Riverside	Benwood	2-5		1
Wheeling	Benwood	2-6		

*Those marked with star belong to the United States Steel Co.

kept on hand. Connellsville coke is higher in ash than that of Durham, but is quite as good in physical structure, and superior to any coke on the Continent. The coal contains from 30 to 35 per cent. of volatile matter. The beehive oven is used almost universally throughout the region, and it is the rule that the coke is made at the mine, but within the last few years a number of by-product ovens have been erected at furnace plants. The coke from Connellsville is used not only near home, but is sent in great quantities to Eastern Pennsylvania, New Jersey and Maryland, northward to Buffalo and Canada and westward to Chicago and Duluth.

Tables XXII-O and XXII-P show the distribution of works in the Pittsburgh district, while Fig. XXII-G illustrates the Edgar Thomson Bessemer plant at Braddock.

TABLE XXII-P.

Steel Works and Mills in the Pittsburgh District.

	Allegheny County, Pa.	Westmoreland, Fayette, and Washington Co's.	Shenango Valley, Pa.	Mahoning Valley, Pa.	Ohio River Counties, Ohio.	West Virginia.	Total.
Bessemer converters (see Table XXII-O).	16	.....	2	4	4	4	30
Open hearth furnaces:							
In large works (see Table XXII-O).....	95	6	19	.....	.....	.....	120
In steel casting plants.....	17	.....	6	.....	.....	.....	23
In crucible plants (see also "Black Diamond," Part I).....	6	.....	1	.....	.....	.....	7
In other small plants.....	9	5	.....	.....	.....	.....	14
Total open hearth furnaces.....	127	11	26	.....	.....	.....	164
Works making crucible steel.....	11	3	3	.....	.....	.....	17
Total number of plants having steel works or rolling mills.....	63	24	28	13	12	12	152
Blast furnaces:							
In large works (see Table XXII-O).....	24	.....	7	3	5	1	40
In small works.....	10	3	12	12	3	2	42
Total blast furnaces.....	34	3	19	15	8	3	82

SEC. XXIIe.—*Chicago:*

The district of Chicago includes the plant at Joliet, Ill., and the rolling mills at Milwaukee, Wis. The metallurgical conditions here are the same as in Pittsburgh. The coke is brought by rail from Connellsville or from West Virginia, the distance ranging from 525 to 625 miles. The strong point of the situation is the short distance through which the ore is brought, and the haul is entirely by lake

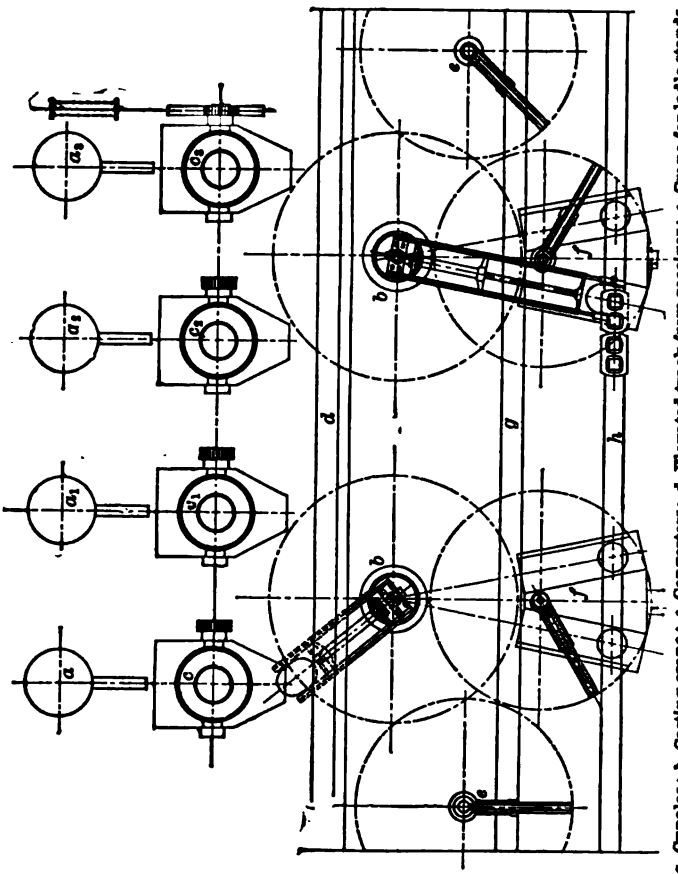
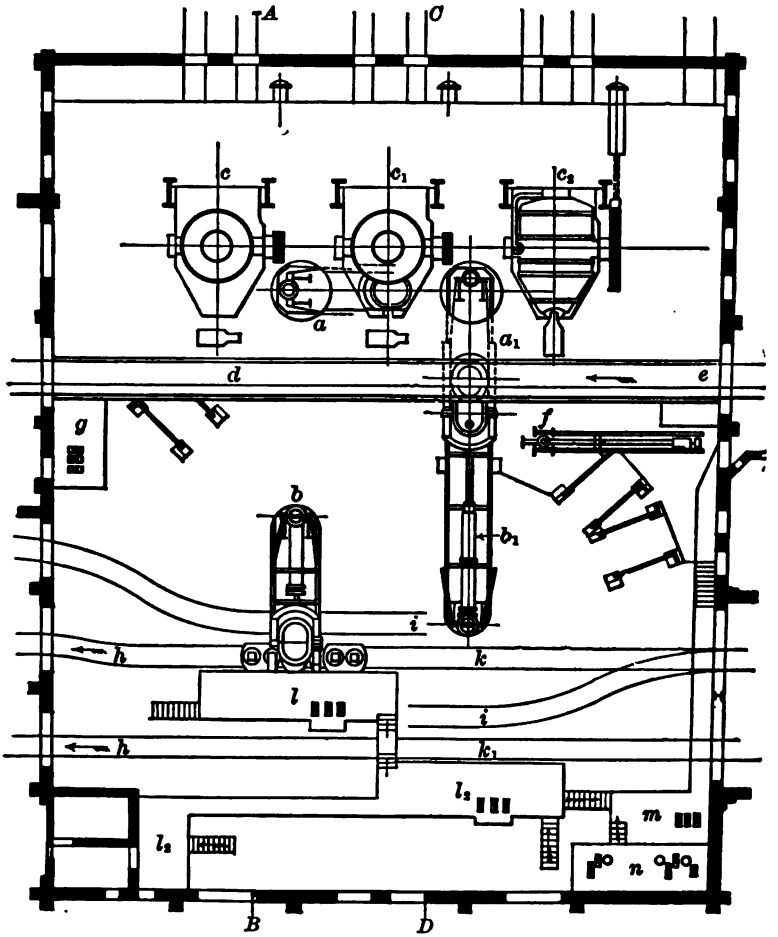


FIG. XXII-G.—BESSEMER PLANT, EDGAR THOMSON WORKS, PITTSBURGH, PA.

vessels, this being cheaper than ordinary ocean transportation owing to the special vessels used. The blast furnaces at South Chicago are on the water front, the vessels being unloaded directly into the stockyard.

The subsidiary fuel comes from different sources. The gas coals of Central Illinois contain as high as 45 per cent. of volatile matter and are used for heating furnaces, but cannot be used in open-hearth work on account of the high sulphur. For this reason the melting furnaces use the gas coal of Pittsburgh, West Virginia and the Big Muddy field of Southern Illinois. Oil has been used in the past, the neighboring refineries, working on Ohio and Indiana oils, supplying residuum at a price which has been attractive.

Chicago is one of the greatest railroad centers of the world, and the manufacture of rails has been the natural direction of develop-



a, Intermediate crane; *b*, Casting crane; *c*, Converter; *d*, *e*, Elevated track from receiver; *f*, Ladle crane; *g*, Operating stand for casting crane; *h*, To stripper; *i*, Slag track; *k*, Casting track; *l*, Casting platform; *m*, Operating casting crane; *n*, Operating converter

FIG. XXII-H.—BESSEMER PLANT AT SOUTH CHICAGO, ILL.

ment, one of the greatest of American rail mills being in operation here. By virtue of the tributary railroad systems the Chicago market has always had a surplus of scrap for disposal, and this fact influenced the development of an extensive open-hearth plant, which

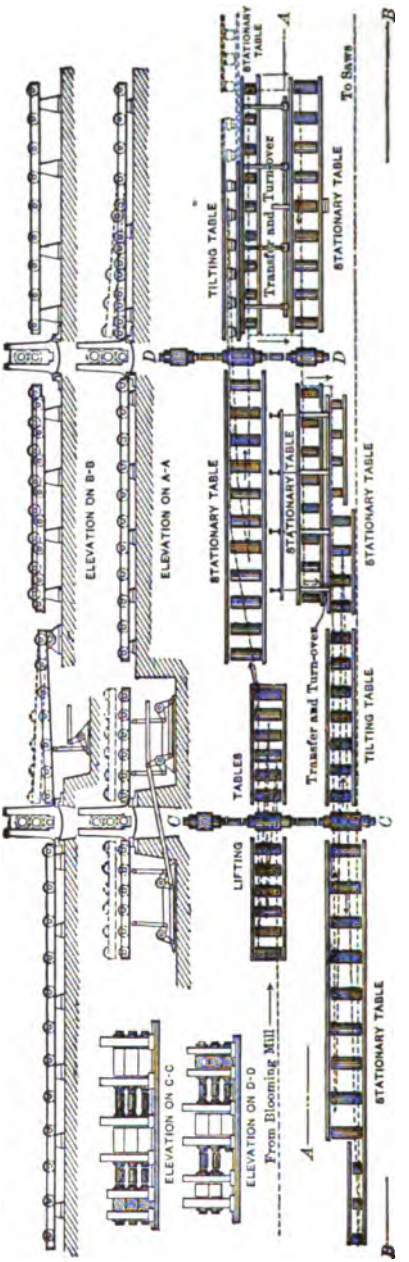


FIG. XXII-I.—RAIL MILL AT SOUTH CHICAGO, ILL.

has been erected within a few years. The plant includes a slab mill, the plates being rolled from slabs. Melted iron is used to a great extent in the open-hearth plant.

The industry of this section is concentrated in the plants of the Illinois Steel Company. The plant at South Chicago embraces ten blast furnaces and a Bessemer plant which feeds a rail mill. The converting department is shown in Fig. XXII-H and the rail mill in Fig. XXII-I. The open-hearth and plate mill plant have already been mentioned. The rolling mill also turns out a certain proportion of axle billets and general merchant billets, the latter being sent to the Bay View works at Milwaukee for finishing into splice plates, small structural shapes and miscellaneous merchant bar. The defective rails are also sent from Chicago to Milwaukee to be rerolled into light rails. At Joliet, about 40 miles away, there is a Bessemer plant, fed partly by pig-iron used directly and partly by iron brought from furnaces at the North and Union Works at Chicago, which is remelted in cupolas. The mills at Joliet roll splice bars, skelp, wire rod and a large amount of sheet bar, and also send billets to the Bay View Works at Milwaukee.

SEC. XXIIf.—*Alabama:*

Note: Most of the facts herein set forth are derived from a comprehensive pamphlet "Iron Making in Alabama," by Dr. W. B. Philips.

The third district in output of pig-iron is the northern central part of Alabama, with Birmingham as its representative, the mines of the Red Mountain group contributing half the ore production of the State. Nowhere else in America is there a great producing district where ore and coal are side by side. The problem in most other districts is the smelting of good ore with good fuel and the making of acid Bessemer steel. In Alabama the conditions are more difficult, and resemble those of some metallurgical centers of the Continent. The ore is of low grade, the limonites being better than the hematites and the richer hematites practically exhausted. A great deal of the coke is made from coal that has been washed in order to lower the ash and sulphur. The phosphorus in the ores is not high enough to render possible the basic Bessemer process, and it is rather high for the basic open-hearth furnace. This does not mean that steel cannot be made in Alabama; it merely means that the cost of conversion will be greater in the long run than in more favored districts, a fact which has not been considered by some investors and metallurgists.

The iron industry of Alabama has suffered from the extravagant statements of promoters, and it may be well to quote from W. B. Phillips, who has done so much to forward the interests of the State, but who has no praise for those who have brought the district into ridicule. I quote this friendly authority to show that what is here written is not put down in malice: "We may keep the great outcrops of ore for a sort of show-place and continue to publish photographs showing 15, 20 and 25 feet of ore as evidence of the prodigality of nature. But there is not a single place on Red Mountain, from Irondale to Raymond, where even 12 feet of ore is mined, and the huge seams taken as a whole are worthless. It is all very well to take visitors to some great cut in the seam, and ask them what they think of *that* for ore. What they will think depends entirely upon how much they know about the ore."*

The ores used in Alabama are of three kinds:

Brown ore=Limonite.

Soft ore=Hematite, carrying about 1 per cent. of lime.

Hard ore=Hematite, self-fluxing.

The composition of each varies very much, and sometimes there are small seams of ore running fairly low in phosphorus, but at no time has any considerable amount been located which would justify the hope of making Bessemer iron on a large scale. Phillips states that the general run of ore as it is smelted will give an iron containing 0.20 to 0.80 per cent. of phosphorus, but in another place (p. 167) he states that no furnace in the State is warranted in guaranteeing under 0.75 per cent. in the pig-iron.

BROWN ORE.

The brown ore or limonite is the best ore in the State and more is being mined every year, but a brown ore bank is a very uncertain proposition; it may yield good material for a number of years, or it may be exhausted in a comparatively short time. Brown ore is a mixture of lumps of ore with a more or less tenacious clay, and a thorough washing is necessary. The average composition at the stockhouse is as follows, it being assumed that all hygroscopic water is expelled:

* Geological Survey of Alabama, 1898, p. 277.

Fe	51.00
SiO_2	9.00
Al_2O_3	3.75
CaO	0.75
P	0.40
S	0.10

SOFT ORE (HEMATITE).

The so-called soft ore of Birmingham is the result of ages of atmospheric influence upon a deposit of hard calcareous hematite. The disintegrating action has not only softened the mass, but the percolating water has removed the lime, and, as a consequence, the percentage of iron is higher in this soft ore than in the underlying hard and limey deposit on the dip. The extent of this decomposed layer varies on the dip, in some places being 300 feet, while in other places the hard ore appears on the surface. When the overburden is stripped off, there is found a seam of ore, quite soft, of a deep red or purple color, the so-called "gouge." It may be only a few inches thick and may run up to two or even three feet. Under this comes the solid ore, diminishing in iron as the depth increases. The best quality of "gouge" will carry 52 per cent. of iron, while ten feet down the limit of good ore is reached. Including this "gouge" it is found that the first ten feet of the seam will average about 47 per cent. in iron, while the second ten feet will run about 42 per cent. In former times the rule was to send to the furnace "anything that was red," but operations are now limited to the upper ten feet. An average of stockhouse samples shows as follows:

SOFT RED ORE.

	Wet.	Dry.
Fe	47.24	50.80
SiO_2	17.20	18.50
Al_2O_3	3.35	3.60
CaO	1.12	1.20
Water	7.00	

HARD RED ORE.

The relation of the deposits of soft and hard ores is shown by Fig. XXII-J, which is copied from Dr. Phillips. Sometimes the hard ore reaches to the surface, and sometimes both soft and hard ores of the good variety are lacking, but usually the hard good ore is found, reaching to a great depth. Not many years ago the soft

ore was the only kind used, but the supply will be exhausted in a short time and furnaces are carrying more and more hard ore, some

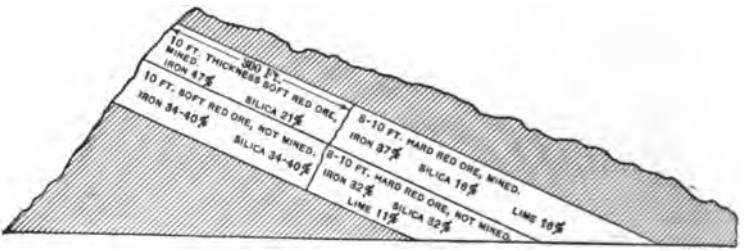


FIG. XXII-J.—ORE DEPOSIT OF BIRMINGHAM, ALA.; VERTICAL SECTION.

plants using it almost alone, and there is a greater proportion of limonite (brown ore).

This hard ore follows the rules that hold for soft ore, that the content of iron decreases toward the dip, but this has nothing to do with the uniformity of the ore at right angles to the dip. The hard ore contains a considerable proportion of lime, the relative amounts of other substances being correspondingly decreased. A general average is as follows:

HARD ORE.

Fe	37.00
SiO_2	13.44
CaO	16.20
Al_2O_3	3.18
P	0.37
S	0.07
CO_2	12.24
Water	0.50

These figures show that the ore is self-fluxing. This is not true of every part of the bed, for some parts give too much silica and some too much lime, but the general fact places in a different light the low content of iron. Dolomite is used quite generally in Birmingham furnaces, the average composition being as follows:

BIRMINGHAM DOLOMITE.

Silica	1.50 to 2.00
Oxide of iron and alumina	1.00
Carbonate of lime	54.00
Carbonate of magnesia	43.00

It is rare to find dolomite thus used, but the results in Alabama seem to show that magnesia will remove the sulphur as successfully as lime.

COAL AND COKE.

The principal coal deposit in Alabama is known as the Warrior field, which raises 85 per cent. of the output of the State, the chief centers being in the counties of Jefferson, Walker and Tuscaloosa. Most of the coal will give a fair coke, but it is necessary to wash it to remove both sulphur and ash. There was a time when furnacemen talked of a fuel ratio of ton per ton, but that day has gone by, and it is now considered good work if a ton of pig is made with 1.3 tons of coke, while the average is higher.

PIG-IRON.

The pig-iron of Alabama has been sent to all parts of the country and much of it abroad. There is a limited demand in the State, but quite a market in Northern cities, as, for instance, Cincinnati, and a great deal is sent by rail and water to Philadelphia, New York and other seaboard points for foundry purposes. Some is carried into the iron districts of Pennsylvania for puddling. The freight rates are low, but the distances are great. The cost of foundry iron in Alabama is usually placed at from seven to eight dollars per ton, and the freight to Northern points is four dollars and even more. The natural answer to this condition is to manufacture the iron on the spot into finished products, and the making of steel is the most attractive field.

TABLE XXII-Q.

Production of Pig-Iron in Alabama.

Year.	Long tons.
1875	22,418
1880	68,925
1885	208,069
1890	816,911
1895	854,667
1896	923,170
1897	947,331
1898	1,093,676
1899	1,093,905
1900	1,184,337
1901	1,225,213
1902	1,472,211
1903	1,561,396
1904	1,459,513

STEEL.

During the last few years great progress has been made in the manufacture of steel in Alabama. At first there was much doubt as to whether it could be successfully made, and enthusiastic articles were written describing the first tap of steel, with figures showing the percentage of carbon, and phosphorus, and sulphur, and everything else, with many more figures about the ultimate strength and elastic limit. It is not alone in Alabama that this nonsense is perpetrated, for leading technical journals gravely copy figures showing the physical results on a piece of steel made in some new district, as if the information were of importance. Nothing can be of less moment.

If iron ore can be found, and fuel brought to it, steel can be made; and by proper attention it can be made equal to the best; and by proper treatment it can be worked into a bar, and that bar will give a definite tensile strength, elastic limit, elongation and reduction of area, depending on the composition of the metal and the rolling conditions, without any regard to the quality of the ore or whether it was mined in Alabama or Japan. The important point is the cost of the finished material, and this can usually be estimated just as well before a pound of steel is made as it can during the first few weeks or months of working. It is necessary to know the general character and location of the ore, and the quality and location of the coal, and some other general conditions, in order to determine the probable cost of pig-iron. It is necessary to know whether the conditions are uniform, and whether the sulphur and phosphorus vary very much, in order to know whether the practice can be reduced to the most economical basis. Knowing these things, it is possible to state whether steel can be made commercially and along what lines the best financial results will be obtained. Following this the operation must be conducted by intelligent metallurgists and by honest managers. Unfortunately, Alabama has lacked these essentials in some notable instances, but there has been continual progress, and it is believed that the steel industry of the State has now acquired a secure footing. The only important works is at Ensley, where the duplex process is successfully operated. No statistics are made public concerning the output of steel, either at this works or in the State.

One of the great drawbacks in the South is the labor question. Owing partly to the climate and partly to the absence of a white population trained to industrial pursuits, it is necessary to depend upon negroes, and they have had no education in this line of work. The greater part of those in the Southern States are entirely improvident, and many will work only long enough to get a little cash. A summary discharge has no terrors, as living is cheap and their wants few. I was told by one of the furnace managers in the South that he has an average of three names on his payroll every year for each job. The two idle men were spending most of their money for liquor and in gambling games, while a certain proportion never worked, but devoted their time to politics, and made speeches on the equality of colored men and their right to occupy the highest positions of the land.

SEC. XXIIg.—*Johnstown:*

The western central part of Pennsylvania is usually considered a district by itself, the statistics including the output of the counties of Cambria, Jefferson, Armstrong, Westmoreland and Fayette. The last two have already been considered as part of the Pittsburgh district, while Jefferson and Armstrong are of little importance. It may, therefore, be well to consider Cambria County by itself, since the plant of the Cambria Steel Company, at Johnstown, is the predominant works in this part of the State. The district produces no ore and the supply is brought from Lake Superior, where the company owns extensive mines in the Marquette, Menominee and Mesabi districts. The coke comes partly from Connellsville and partly from a new installation of by-product ovens which runs on the leaner coals drawn from mines within the limits of the works.

The plant has four converters and fifteen 50-ton furnaces. It not only makes a large tonnage of standard rails, but is an important factor in beam and structural work, and has large special shops, called the Gautier Department, wherein special steels are worked into springs, forks and a thousand similar products.

SEC. XXIIh.—*Steelton:*

Ranking fifth among the pig-iron and steel-producing districts of the United States is the district of Dauphin and Lebanon counties, in Pennsylvania. More than half of all the pig-iron is made in the furnaces of The Pennsylvania Steel Company and most of the steel at its plant at Steelton, near Harrisburg.

The feature of this district is the deposit of ore at Cornwall, near Lebanon. The hills in which the ore occurs were held in private hands from 1732 down to 1894; but in that year the Lackawanna Iron and Steel Company acquired a one-third interest and in 1901 The Pennsylvania Steel Company bought a still larger share. This mine has been worked since 1740, and up to the end of 1904 had produced 18,000,000 tons of ore, which was more than had been obtained from any other one mine in the United States, and up to 1893 it was the largest single producer. The Port Henry mines in New York have raised two-thirds as much, having been operated since 1804. The present rate of production at Cornwall is 750,000 tons per year, and there is no other mine north of Alabama and east of Michigan which raised as much as 110,000 tons in 1903. The ore is a magnetite, low in phosphorus, but intimately mixed with clayey matter, and the deposit is permeated by streaks of copper-bearing sulphides. Some streaks can be separated, but there is such a mixing of the minerals that the ore as mined contains a considerable quantity of both of these elements. The copper varies, but the pig-iron from selected ore will contain about 0.60 per cent. of copper, while the run of the mine will give a somewhat higher proportion.

The sulphur will run from 2 to 2.50 per cent., and roasting is always practiced, about half the sulphur being removed in this way. The run of the mine contains from 40 to 42 per cent. of iron and 20 per cent. of silica, with a small proportion of lime and magnesia. The roasted ore contains from 1 to 1.25 per cent. of sulphur, and 40 per cent. of iron, so that in order to make 100 pounds of pig-iron, the ore will carry from 2.5 to 3 pounds of sulphur into the furnace. There will also be needed about 1.5 tons of coke carrying 1 per cent. of sulphur, or 1.5 pounds per 100 pounds of iron, and there will, therefore, be from 4 to 4.5 pounds of sulphur added per 100 pounds of iron. In ordinary blast-furnace practice, where the ore has no sulphur and the fuel ratio is one to one, the total sulphur per 100 pounds of iron will be 1 pound, so that in using Cornwall ore the sulphur in the burden is from four to five times as much as in ordinary practice.

It is, therefore, necessary to run the Cornwall furnaces extremely hot, in order to make good iron, and, as a consequence, the iron is high in silicon, usually containing over 2 per cent. and frequently

from 3 to 4 per cent. For thirty years this iron has been used in making Bessemer steel at Steelton, usually forming about one-third of the charge, but sometimes it has been converted alone. It has also been used by the Lackawanna Company at their Scranton works for the manufacture of rails. Quite a large amount of iron is sold to makers of steel castings and for use in acid open-hearth furnaces, because the phosphorus in the pig-iron is below .04 per cent.

There are several blast furnaces in the vicinity of the Cornwall banks, some owned by The Pennsylvania Steel Company, some by private individuals, and some by the Lackawanna Company, but the only large steel works in the district is The Pennsylvania Steel Company at Steelton. This company was not the first to produce Bessemer steel in this country, but it was the first to make it regularly on a commercial scale, the Bessemer plant being built in 1868. During the last ten years this company has expanded in several directions:

(1) By building a rail mill and shipyard at Sparrow's Point, near Baltimore, known as the Maryland Steel Company.

(2) By making a specialty of frogs, switches and general railway equipment, the plant at Steelton being the largest in the country.

(3) By enlarging its open-hearth departments for making special steels.

(4) By the development of a bridge shop which has become widely known for some very large operations, among which may be mentioned the following:

Niagara steel arch, 550 feet span, double-track railroad.

Duluth drawbridge, 500 feet draw span.

Gotkeik viaduct in Burmah, 320 feet high, 2280 feet long.

The new East River Suspension Bridge, 1700 feet span.

Between Steelton and Harrisburg are the plate rolling mills of the Central Iron and Steel Company. Fig. XXII-K shows the Bessemer plant at Steelton, and Fig. XXII-L a cross-section of the open-hearth department.

SEC. XXIIi.—*Sparrow's Point.*—The iron and steel industry of Maryland is represented by the Maryland Steel Company, an extension of The Pennsylvania Steel Company, of Steelton, Pa. It was started on new ground in the year 1887, on the Chesapeake

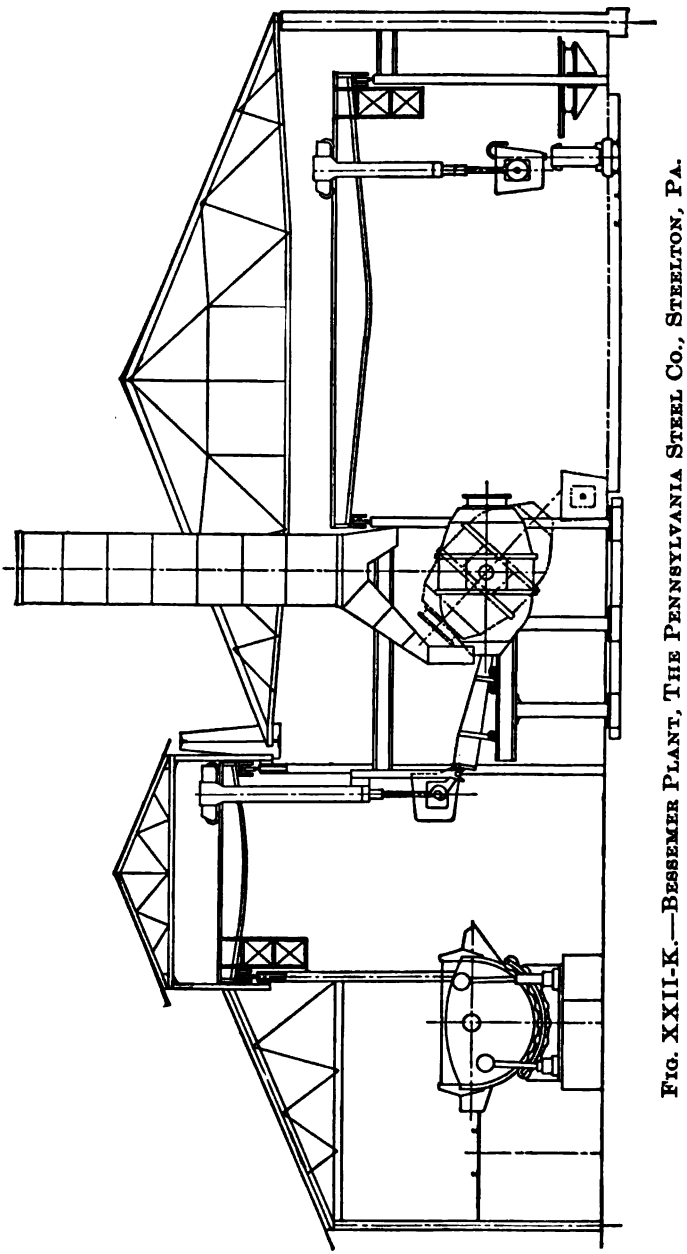


FIG. XXII-K.—BESSEMER PLANT, THE PENNSYLVANIA STEEL CO., STEELTON, PA.

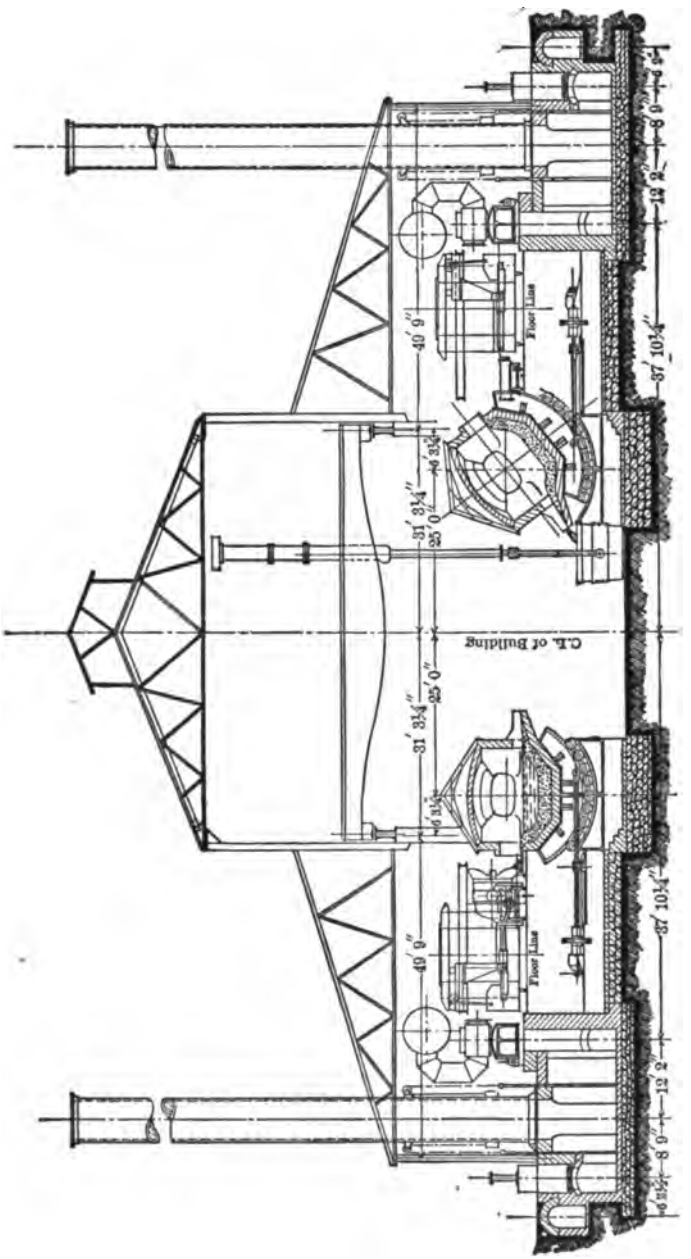


FIG. XXII-L.—CROSS-SECTION OF OPEN-HEARTH PLANT AT STEELTON.

Bay, about 15 miles south of Baltimore, and ocean steamers bring ore from the mines in Cuba to the stockyard of the blast furnaces. The Pennsylvania Steel Company was the first to develop the Cuban deposits, its Jurugua mine having been opened in 1884. The Spanish-American Iron Company followed, but has since been bought by The Pennsylvania Steel Company. Table XXII-R shows the shipments from the Cuban mines since their opening, and the composition of the ore.

The steel plant at Sparrow's Point consists of two 18-ton converters, and these supply a mill which rolls either rails or billets, the piece being finished from the ingot without reheating the bloom. This plant also has one of the largest shipyards in America. In the construction of the Bessemer plant there were two radical innovations introduced by its now president, F. W. Wood. The old swinging hydraulic ladle cranes were discarded, and a traveling crane introduced for the first time. The most radical change was in plac-

TABLE XXII-R.

Shipments of Ore from Southeastern Cuba; gross tons.

Year.	Jurugua Iron Co.	Spanish American Iron Co.	Sigua Iron Co.	Cuban Steel Ore Co.	Total.
1884 to 1889 incl. av. per year..	129,780	.....	.....	.....	129,780
1890 to 1894 incl. av. per year..	291,464	.....	4,088	.....	295,552
1895 to 1899 incl. av. per year..	220,025	139,034	.....	.....	359,059
1900.....	154,871	292,001	.....	.....	446,873
1901.....	199,764	334,833	.....	17,651	552,248
1902.....	221,039	455,105	.....	23,590	699,734
1903.....	157,230	467,628	.....	.....	624,858
Total to end of 1903.....	4,069,025	2,244,746	20,438	41,241	6,375,450
Total to foreign ports.....	.....	.....	.....	.....	80,902
Aver. composition of cargoes.					
Fe.....	57.00	63.30	65.85	62.80	.....
S.....	0.288	0.092	0.037	0.211	.....
P.....	0.025	0.033	0.015	0.036	.....

ing the molds on trucks for casting. A mechanical stripper then removes the molds from the ingots in close proximity to the heating furnaces. This arrangement is now familiar through its universal adoption. A minor novelty in this plant, but an advance in line with more recent progress, was the installation of the Besse-

mer blowing engine near the blast-furnace boilers to use the excess power developed at the smelting plant.

During the last few years the Maryland Steel Company, or, as it is often known from its location, "Sparrow's Point," has furnished a great proportion of the rails exported from America. This is a natural result of its situation, and of the fact that there is no duty on the iron ore which goes into articles of export. Following is a statement showing the steel rolled from 1898 to 1901, with the amount exported. Fig. XXII-M is a plan of the rolling mill at Sparrow's Point, while Fig. XXII-K gives a cross-section of the Bessemer plant at Steelton, Pa., showing the method of casting on trucks:

	1898	1899	1900	1901
Production.	130,804	225,645	225,618	277,853
Exported	63,972	85,976	102,254	83,673
Per cent. export.....	48.9	38.1	45.3	30.1

SEC. XXIIj.—*Lake Erie:*

The ore for the furnaces of Pennsylvania comes down the Great Lakes and is unloaded on the shore of Lake Erie. A furnace at the port of entry will have no land freight to pay on the ore, and will haul less than one ton of coke, while the furnaces near the fuel must haul $1^2/_3$ tons of ore. The proposition is simple from a mathematical standpoint, but there are circumstances which disturb the calculations, for a position on the shores of Lake Erie does not increase the sphere of commercial influence as much as might be expected. On the north the tariff of Canada bars the way, while on the west is the competition of Chicago. There is no reliable communication eastward; the falls at Niagara have given rise to two canals, one on American territory to New York by way of the Hudson River, and one in Canada, the Welland Canal, connecting with the St. Lawrence. Great sums have been spent by Canada to create an economical way of shipping by water from her western provinces to the ocean, but she is struggling not only with a commercial but a political complication. The navigation of the St. Lawrence from Quebec to Montreal is not satisfactory, but the latter place will not allow Quebec to get all the trade. Consequently much money is spent to improve the river channel, which can be used only a part of the year, when there already exists a subsidized government railway which can carry the freight to Que-

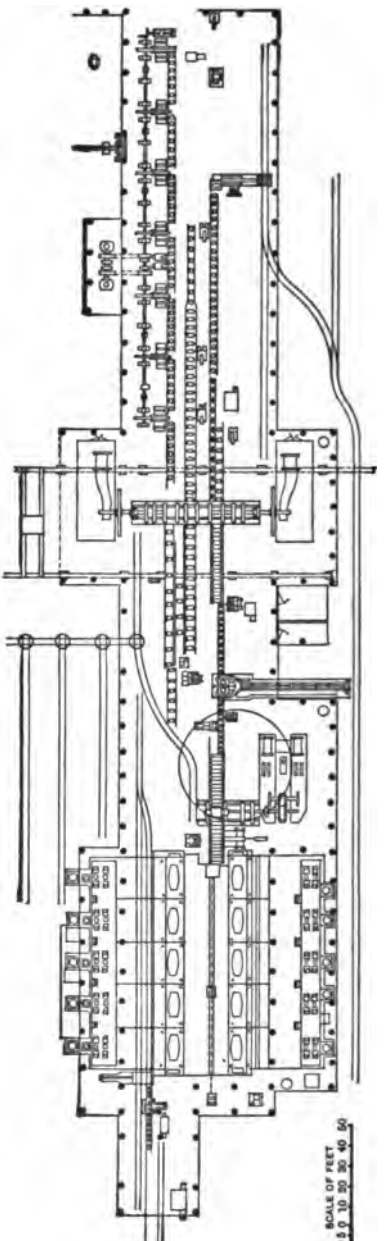


FIG. XXII-M.—RAIL MILL OF MARYLAND STEEL CO., SPARROW'S POINT, MD.

bec at less cost. The same condition exists to some extent in the United States, where the people are urged to make a ship waterway out of the present Erie Canal, when the interest on the money needed to do this would probably pay the freight by railroad on all the material brought down. In both the case of the Canadian and American canals there is the serious objection that traffic is entirely suspended for three or four months in the winter, while in the case of the St. Lawrence River there is the additional disadvantage that the navigation of the lower bay for several hundred miles is very dangerous, on account of the prevailing fogs. Of late years the question of marine insurance has become a serious matter.

All of these matters have an important bearing on the question of locating a steel plant on Lake Erie, as proven by the stress laid on water transportation by canal and by the St. Lawrence when each new project is started. These objections, however, are by no means prohibitory. The advantages are self-evident, and it may be said that the trend of new enterprises is toward this district. One of the first to make the journey was the Lorain Steel Company. There had been for some years a rolling mill near Johnstown, Pa., which bought blooms from the Cambria Company and made rails for street railways. A new works was built near Cleveland, equipped not only for street or "girder" rails, but for standard rails, a complete blast furnace and Bessemer plant being erected on entirely new ground, but the work on frogs, switches and special work is still done at Johnstown. Since that time Lorain has been one of the centers of steel production in the United States. It divides with Steelton the work of making all the rails and most of the equipment for the street railways of the United States, and both of these plants have taken a part in foreign trade in this line of work.

The more immediate vicinity of Cleveland has played a very important part in the steel industry of this country for a long period. The Otis Steel Company was one of the pioneers in the manufacture of open-hearth firebox steel, and its name has been known all over the land. The Cleveland Rolling Mill Company was a factor in the rail situation twenty years ago, but has long since turned its product into special work, it being one of the largest producers of wire rod in the country.

In 1903 the new plant of the Lackawanna Steel Company was

put in operation near Buffalo. This includes all necessary blast furnaces, a Bessemer plant of four 10-ton vessels, two rail mills, a structural mill and a merchant mill, and will include open-hearth furnaces and plate mills. When completed it will be among the largest plants of the world. The most radical departure in its construction is in an extensive plant of gas engines, both to blow the furnaces and to furnish electric power.

SEC. XXIIk.—*Colorado:*

The only great iron district west of the Mississippi River is at Pueblo, Colo., but its tributary mines cover an area which would overshadow a European empire. The Colorado Fuel and Iron Company owns over 30 mines in the State and 5 mines in New Mexico. The coke comes from southern Colorado, about 90 miles from Pueblo, the coal containing 30 per cent. of volatile matter, and occurring in beds about 6 feet thick. It is washed and gives a hard coke containing 16 per cent. of ash. The steam and gas coals are brought 50 miles. In Colorado can be found coals of every description from anthracite to lignite, the beds having been exposed to severe geologic disturbances and volcanic intrusions.

The iron ore comes from three sections. At Sunrise, Wyo., 350 miles from Pueblo, there is an enormous deposit of red hematite running as high as 62 per cent. in iron, which can be mined with a steam shovel. At Fierro, N. M., 600 miles from Pueblo, is a large deposit of hard magnetic ore running up to 61 per cent. in iron. At Orient, Colo., 125 miles from the works, is a deposit of easily reducible limonite containing 50 per cent. of metallic iron. All of these ores are within the Bessemer limit of phosphorus. At Leadville, 100 miles away, there is a deposit running 30 per cent. in manganese, and in eastern Utah, about 400 miles distant, one with 50 per cent. of manganese. The spiegel for the steel plant is smelted at the Minnequa plant at Pueblo.

This district is protected by a great distance, and a high transportation charge, from the competition of Eastern works, and has an enormous area as its natural market. The country is sparsely settled, but with the constant westward trend of population, the wants of railroads and other users have increased, and there is a demand for a large works.

The plant, when completed, will have five blast furnaces, a Bessemer plant with two 15-ton converters, an open-hearth plant with

six 50-ton basic furnaces, one 40-inch blooming mill, 24-inch reversing structural mill, rod, sheet, tin plate, wire and nail mills.

SEC. XXIII.—*Eastern Pennsylvania:*

In addition to the Steelton district, already described, there are several seats of industry which should be mentioned in the eastern portion of Pennsylvania.

The Bethlehem Works was formerly one of the great rail producers, but has not rolled rails for many years. It is now engaged in making open-hearth steel forgings and has the most complete plant in the country for this work. It divides with the Carnegie Steel Company the work on armor plate for the war vessels of the United States, and turns out guns and shafts of the largest size.

In the neighborhood of Philadelphia are the Midvale Steel Company and the Pencoyd Works, the Phœnixville Iron and Steel Company and the Tidewater Steel Company. The first of these does a large amount of work in the line of special steels and forgings, while Pencoyd and Phœnixville are known as bridge and structural shops. The Pencoyd Works came into general notice beyond the boundaries of the United States on account of the well-known Atbara Bridge in the Soudan.

Considerable pig-iron is made in eastern Pennsylvania. In the Lehigh Valley there are twenty-nine furnaces, and eighteen along the Schuylkill. Most of the product goes into the general foundry trade, but some is used in the neighboring steel plants. During recent years these furnaces have quite generally used the ores of Lake Superior with Connellsville coke.

In the neighborhood of Chester, not far from Philadelphia, there is a concentration of steel-casting plants, this being one of the centers in this line of work, while Coatesville, Pa., is prominent for its plate mills.

I have divided eastern Pennsylvania in a way somewhat different from that followed by Mr. Swank. He puts the Schuylkill Valley separate, but does not include Philadelphia, which lies on both sides of this river. I have combined, under the title of southeast Pennsylvania, the plants of the Schuylkill Valley with those of Philadelphia, Chester and Delaware counties.

Table XXII-S gives a list of the plants in this district and shows its importance as a steel producer.

TABLE XXII-S.

Steel Plants in Southeastern Pennsylvania.

	Location.	Open Hearth Furnaces and Capacity.	Tropenas, Converters and Capacity.
Steel Works with Rolling Mills:			
Lukens	Coatesville...	6-40 6-50	.....
Pencoyd	Philadelphia.	10-30	.....
Phœnix	Phœnixville.	4-40 4-30	.....
Worth Brothers	Coatesville...	6-35	.....
Tidewater	Chester	3-50	.....
Midvale	Philadelphia.	?	.....
Steel Casting Plants:			.....
Thurlow	Chester	2-20 2-12	.....
Penn Steel	Chester	3-25	.....
Solid	Chester	2-20	.....
Seaboard	Chester	2-20	.....
Chester	Chester	1-20	.....
Norristown	Norristown ..	2-15	.....
Wharton	Philadelphia.	.....	1-2
Brygton	Reading	.....	2-2
Logan	Phœnixville.	.....	2-2

SEC. XXIIm.—*New Jersey, New York and New England:*

On the shores of Lake Champlain and in the northern basin of the Hudson River there are considerable deposits of magnetite, which played an important part in the early history of the American iron industry, being the base of supplies for the Bessemer plant formerly operated at Troy, N. Y. It was necessary to transport either coke or anthracite coal from Pennsylvania, and with the advent of cheap Lake Superior ores the manufacture of steel at this point was abandoned many years ago. An attempt was made in recent years to operate a basic Bessemer plant, but the conditions were not such as to warrant a continuance of the operations. This line of magnetic deposits extends southwesterly across the northern portion of New Jersey into Pennsylvania, where it appears as the Cornwall ore hills. The ore varies throughout its length, its main point of resemblance being its magnetic property. In its northern extension titanium is distributed in prohibitive quantities. In the south this element is absent. Many mines have been worked in New Jersey in years gone by, but either from the exhaustion of the deposits or from the inferior quality or from the high cost of mining, a large number have ceased operation, so that the amount now produced in the State is only half what was raised in 1880.

Taking the whole magnetic field from northern New York to southern Pennsylvania, the Cornwall deposit, described under the Steelton district, produces half the total, while New York and New Jersey divide the remainder with an annual production of 300,000 tons each. The iron made in these two States enters, to a limited extent, into the steel industry, some of it being sold to open-hearth furnaces, but most of it is used in the general foundry trade. Much money has been spent on concentrating plants throughout this whole region, the most extensive outfit having been erected in northern New Jersey by Edison. The ore used by him contained only 18 per cent. of iron and was a hard rock, so that the expense per ton of finished concentrate was heavy. The operation of bricking was not satisfactory and the whole work was discontinued about two years ago, but in other places less ambitious installations have been worked with success.

Most of the steel plants of this district are local in character, some running exclusively on steel castings. By far the most important producer is the South Works, at Worcester, Mass., which has eight open-hearth furnaces supplying wire mills. This is owned by the United States Steel Corporation. No other plant in these six States has as many as six furnaces. In no works east of Pennsylvania is there, today, a complete plant of blast furnaces, steel producers and rolling mills, nor is there a standard Bessemer converter in regular operation.

Table XXII-T gives information concerning the distribution by States.

TABLE XXII-T.

Iron and Steel Plants in New England, New York and New Jersey.

State.	Blast Furnaces.		Bessemer Plants.		Open Hearth Plants.		Works making crucible steel.	Works having rolling mills
	Coke.	Charcoal.	Works having standard converters.	Works having special converters.	No. of works.	No. of furnaces.		
Maine	.....	.....	.....	.....	.....	.....	.....	1
Massachusetts	.....	3	.....	1	4	14	1	7
Rhode Island	.....	.....	.....	.....	1	2	.....	2
Connecticut	.....	4	.....	1	1	1	2	5
New York	16	3	.....*	.....	6	11	3	21
New Jersey	11	....	.....	.....	4	9	5	17
Total	27	10	.....	2	16	37	11	53

*The Troy works is idle.

CHAPTER XXIII.

GREAT BRITAIN.

SECTION XXIIIa.—*General view.*—As far as the iron industry is concerned, the term Great Britain embraces only England, Wales and Southern Scotland. These divisions cover an area equal to Pennsylvania and Ohio combined, but embrace three or four times as great a population. The pig-iron production of Great Britain in 1904 was 8,562,000 tons, while the two States mentioned made 10,622,000 tons. In both cases a great part of the ore was brought a long distance by water, to England by the ocean and to Pennsylvania by the Lakes, but Great Britain was compelled to find a foreign market for nearly half her product, while the home demand in America took care of all but a small proportion of the output. Fig. XXIII-A shows the districts into which the country may be conveniently divided, the statistics being from the Home Office Reports. Lack of room makes it difficult to locate the squares exactly as the statistics would require; it must, therefore, be remembered that Barrow is in Lancashire, and hence the product of the Barrow Steel Works is included in the lines shown in the southern portion of the county. The map is a general guide, but not an accurate diagram. The statistics on the map are for 1899, but later figures are given in Table XXIII-B.

Fig. XXIII-B shows the coal fields of Great Britain.* Most of the coal gives a good coke, that of Durham being noted for its excellent quality. In 1903 the exports of coal were 44,950,057 tons, of which 19,881,773 tons came from South Wales, 15,535,557 tons from the Northeast Coast, and 7,174,366 tons from Scotland, these three districts supplying 96 per cent. of all the coal exported. There were 717,477 tons of coke sent over sea, and of this South Wales contributed 102,244 tons, Scotland 59,210 tons, while the Northeast Coast shipped 463,351 tons. The Durham district, there-

* *Les Charbons Britainques*; Lose; Paris, 1900.

fore, supplied only one-third of the coal exported, but furnished two-thirds of the coke. The coal was shipped to all parts of the world, France taking the most—6,976,467 tons; Germany 6,110,101 tons, Italy 6,278,333 tons, and Russia 2,442,478 tons—almost all to her northern ports. The Pacific Coast of the United States took 72,373 tons, while the Atlantic Coast had 1,070,230 tons. The coke also was spread all over the earth; out of a total of 717,477 tons exported, the best customer was Spain and the Canaries with 142,583 tons; next Norway, with 95,229 tons; northern Russia, 28,156 tons; Sweden, 58,300 tons. Of the iron-producing nations Germany took 5,871 tons, France 16,301 tons, Austria 8,501 tons, and the Pacific Coast of America 32,388 tons. The shipments to Spain and to northern Russia are important, since these two districts depend upon outside sources for their fuel.

The steel industry of England is largely dependent upon foreign ore. In 1865 the imports of ore were not over 10,000 tons per year. In 1867 they had risen to 86,568 tons; in 1870 to 400,000 tons, and in 1880 to 3,000,000 tons. The imports, as shown in Table XXIII-A, now amount to over 6,000,000 tons per year,

TABLE XXIII-A.

Imports of Iron Ore into Great Britain.

	1882	1886	1890	1895	1900	1903
Spain	3,072,955	2,533,989	3,627,646	3,807,188	5,551,559	4,945,086
Greece	.....	17,989	79,007	193,353	304,648	316,648
Sweden	.....	.....	.....	80,904	93,055	244,999
Algeria	91,097	201,601	205,670	162,525	141,624	222,619
France	.....	.....	.....	.....	48,165	130,078
Norway	.....	.....	.....	.....	.....	123,611
Italy	40,231	35,546	79,312	127,317	88,532	111,197
Newfoundland	.....	.....	.....	.....	.....	49,536
Other countries	31,663	33,543	39,630	79,024	65,380	107,204
Total	3,284,946	2,822,598	4,031,265	4,450,311	6,297,963	6,250,978

about 80 to 90 per cent. of which comes from Spain, where some of the largest English companies own ore properties. Greece and Algeria have been the most important sources of supply next to Spain, but recently Sweden has come to the front with increasing shipments each year. This ore goes to the north, south, east and west. The Northeast Coast gets 2,000,000 tons per year, Scotland 1,600,000 tons, South Wales 1,200,000 tons, and the West Coast

1,100,000 tons. This imported ore is put into acid steel, while most of the native ore goes into basic steel or wrought-iron, or into the general pig-iron supply.

The distances through which material is carried are small in comparison with those in America. From the Scotch iron works south of Glasgow to the coal mines of South Wales is less than three hundred miles in a straight line, while across the island from the works at Barrow to the coke fields of Durham is only 111 miles by railroad. On this account, the works in England have arranged themselves not so much with relation to their raw material as to a market for their output. Cardiff and Glasgow bring ore across the sea to their coal beds, while Middlesbrough brings the fuel to the ore, and Barrow pays freight on a part of both fuel and

TABLE XXIII-B.

Output of Coal, Ore, Iron and Steel in Great Britain in 1903.

District.	Coal; Tons.	Ore; Tons.	Pig Iron; Tons.	Blast Furnaces		Wrought Iron; Tons.
				Total.	Active.	
North Yorkshire (Cleveland).	2,645	5,677,560	2,067,163	75	52	119,087
Durham and Northumberland	35,873,293	13,468	1,040,887	39	29	.....
Scotland (Ayr and Lanark)...	21,376,129	546,893	1,290,790	97	84	196,078
South Wales.....	41,453,754	39,167	883,227	57	20	.....
South Yorkshire (Sheffield)...	28,527,958	46,375	298,406	24	15	124,341
West Coast.....	26,725,237	1,490,549	1,485,785	76	39	132,588
Staffordshire.....	13,037,553	738,549	585,330	65	31	305,819
North Wales.....	3,184,136	.....	*50,000	5	3	.....
Eastern Central District.....	14,097,750	4,479,578	639,750	45	28	.....
Derby and Nottingham	23,851,048	20	546,947	51	38	34,113
Other districts.....	22,204,966	683,486	46,778	21	10	38,367
Total.....	230,334,469	13,715,645	8,935,063	555	349	950,393

*Estimated.

District.	Production of Steel; tons.				
	Bessemer.		Open Hearth.		Total of Bessemer and Open Hearth.
	Acid.	Basic.	Acid.	Basic.	
North Yorkshire (Cleveland).	24,668	396,859	755,044	139,784	1,256,355
Scotland.....	.....	.....	865,953	38,897	904,850
South Wales.....	400,895	.....	650,993	.....	1,051,888
South Yorkshire (Sheffield) ..	239,279	84,279	156,474	68,080	548,112
West Coast.....	652,073	.....	125,136	38,204	815,413
Staffordshire.....	.....	*171,965	59,674	161,098	392,737
North Wales.....	.....	.....	.....	64,746	64,746
Total.....	1,316,915	593,103	2,613,274	510,809	5,034,101

* Including Scotland.

ore; but in each case the works is on tidewater, an important factor in a nation that depends on foreign trade. In other cases there are local conditions, as in Staffordshire and South Yorkshire, where, during long years and even centuries, there have grown up

TABLE XXIII-C.

Output of Pig-Iron in Great Britain; one unit=1000 tons.

District.	1830	1870	Average 1882 to 1885 incl.	Average 1886 to 1890 incl.	Average 1891 to 1895 incl.	Average 1896 to 1900 incl.	Average 1901 to 1908 incl.
Northeast Coast..	5	1627	2619	2642	2638	3194	2963
West Coast.....	.....	678	1603	1589	1284	1576	1486
Scotland.....	37	1206	1069	922	826	1128	1228
South Wales.....	278	1073	871	807	734	770	830
Eastern Central...	.....	75	428	505	494	641	600
Staffordshire	213	892	550	542	506	586	556
Central.....	18	180	437	388	417	521	508
South Yorkshire..	29	78	260	197	213	296	276
Others.....	98	155	252	167	133	177	62
Total.....	678	5964	8086	7759	7245	8889	8514

industries, like those of Sheffield and Birmingham, that call for large quantities of steel and iron to be worked into finished articles of commerce.

In considering the short distances covered by raw material it is necessary to remember that freight rates are much higher in England than in America. In 1900 the charge for carrying a ton of pig-iron from South Staffordshire to London, a distance of 120 miles, was from $2.40 to $2.90, and for carrying coke 100 miles from South Durham to Cumberland the rate was $1.80 per ton. In the United States the rate on pig-iron from Pittsburgh to Philadelphia, in the same year, a distance of 353 miles, was $1.77.. On coke between the same points it was $1.95. The rate on coke is over three times as high as in America, while on pig-iron it is four to five times as much.

Both Scotland and Middlesbrough have specialties in the shipbuilding industries on the Clyde and the northeast coast. The vessels launched each year in England foot up from 1,000,000 to 1,500,000 tons, and, by a rough estimate, this means from 350,000 to 500,000 tons of steel and iron, or, say, one-twelfth of all the wrought-iron and steel made in the Kingdom.

Table XXIII-B gives more information concerning the iron in-

dustry in 1903, while Tables XXIII-C, D and E give the results of an inquiry into the iron trade during the last twenty years. It is shown that the English iron industry is in a stationary condition. The output of ore has decreased in the last twenty years, but

TABLE XXIII-D.

Output of Iron Ore in Great Britain; one unit=1000 tons.

District.	1860	1870	1880	Average 1886 to 1890 incl.	Average 1891 to 1895 incl.	Average 1896 to 1900 incl.	Average 1901 to 1903 incl.
Northeast Coast...	1484	4208	6528	5416	4700	5639	5458
Eastern Central...	118	1048	2765	2897	2974	4018	4130
West Coast.....	990	2093	2759	2569	2199	1943	1540
Staffordshire.....	1543	1378	1798	1341	925	1025	793
Scotland.....	2150	3500	2864	1226	785	867	505
Bristol Channel...	823	865	534	197	160	120	33
Central.....	376	385	153	15	11	4	2
South Yorkshire..	256	308	287	78	72	56	.....
Others.....	279	496	538	286	229	339	679
Total.....	8024	14371	18026	14025	12055	14061	13140

is now increasing, owing to the development of the lean ore beds of Leicestershire, Lincolnshire and Northamptonshire. There has been a decided increase in the amount of ore imported, and the production of pig-iron has been thus sustained, but the rate of increase in production of iron and steel has been less in the case of

TABLE XXIII-E.

Imports of Ore into Great Britain at Different Points.

	Average 1882 to 1885 inclusive.	Average 1886 to 1890 inclusive.	Average 1891 to 1895 inclusive.	Average 1896 to 1900 inclusive.	Average 1901 to 1903 inclusive.
Northeast Coast.....	948,000	1,488,000	1,920,000	2,354,000	2,051,000
Bristol Channel.....	1,434,000	1,347,000	1,183,000	1,387,000	1,257,000
Scotland.....	382,000	575,000	694,000	1,294,000	1,640,000
West Coast.....	294,000	317,000	166,000	382,000	1,124,000
Others.....	11,000	15,000	15,000	31,000	29,000
Total.....	3,069,000	3,742,000	3,978,000	6,048,000	6,101,000

England than in any of the other leading nations. For the sake of comparison I have calculated the average output per year for the five years from 1880 to 1884 inclusive, and for the five years from 1899 to 1903. In the case of Russia the output of pig-iron in the

later period was 5.20 times what it was some twenty years earlier. The other nations gave ratios as follows: United States, 3.71;

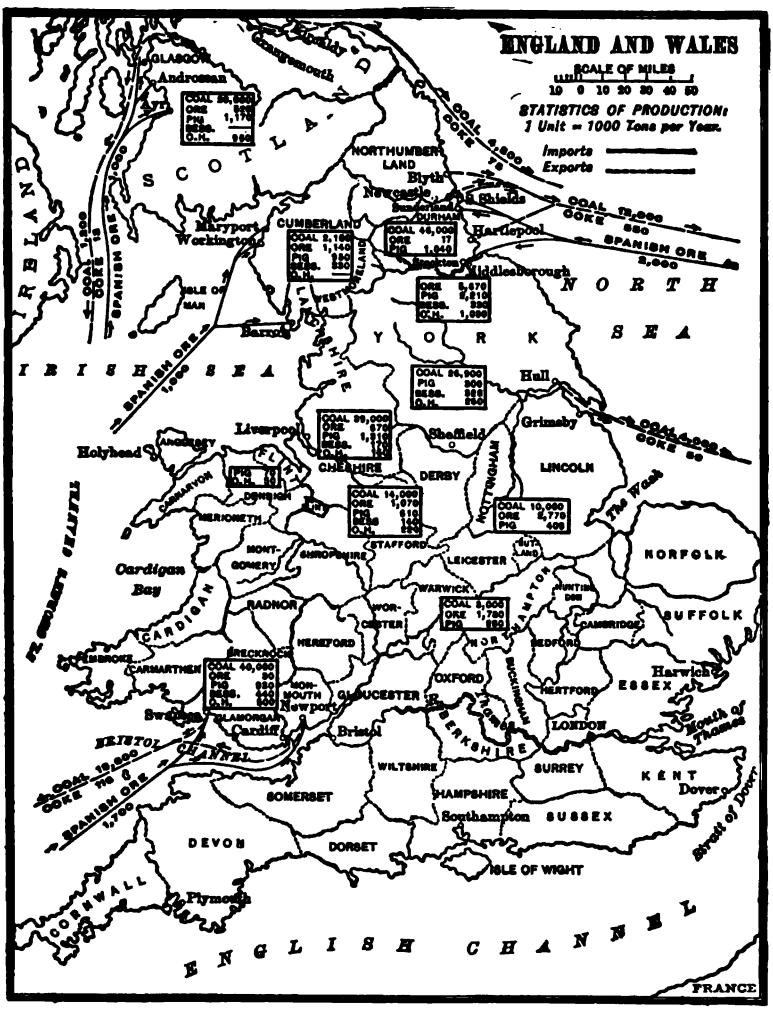


FIG. XXIII-A.

Germany, 2.68; Austria-Hungary, 2.26; Belgium, 1.47; France, 1.35; Sweden, 1.24; Great Britain, 1.08. The records of steel output gave the following ratios of increase: United States, 8.21;

Germany, 7.35; Russia, 6.69; Sweden, 6.33; Austria-Hungary, 5.12; Belgium, 4.46; France, 3.52; Great Britain, 2.68. It is clear

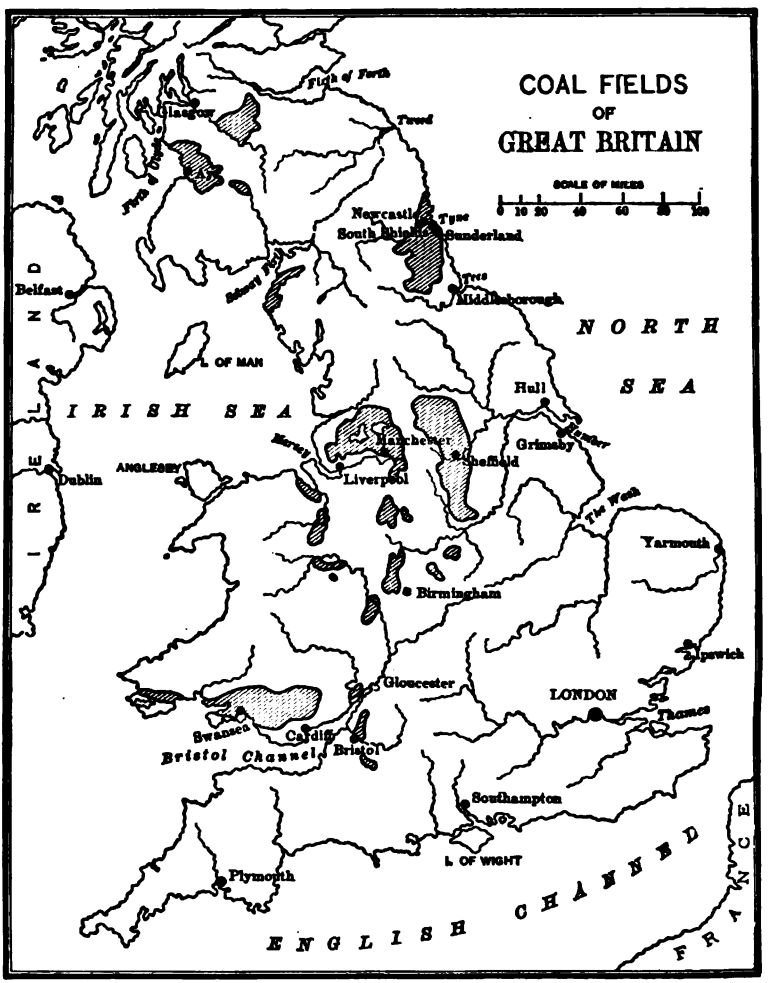


FIG. XXIII-B.

that during the last twenty years the rate of increase in output has been less for England than for any other country in both pig-iron and steel.

SEC. XXIIIb.—*The Northeast Coast.**—The Northeast Coast is the great iron and steel district, making one-third of all the pig-iron and one-quarter of all the steel of the Kingdom. Middlesbrough is the center where the coke of Durham meets the ore from Spain, or from the Cleveland Hills, and the finished steel finds an outlet either in the shipyards along the Tees, or by water to other ports of the kingdom, or of other countries. The Cleveland beds produce 40 per cent. of all the ore raised in the island. This is smelted in the neighborhood of the mines, and out of a total of

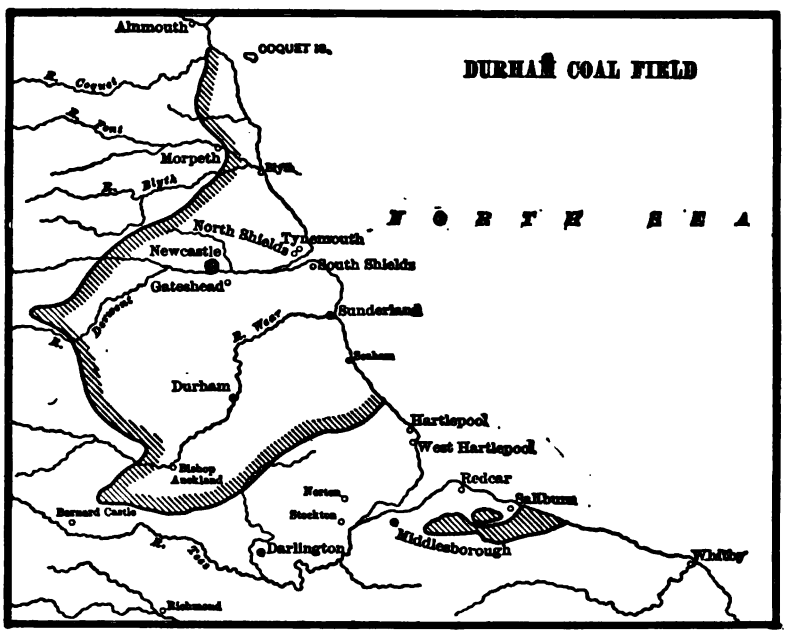


FIG. XXIII-C.

79 blast furnaces in operation in the Northeast in 1901 there were 43 smelting Cleveland ore. A small proportion of Cleveland iron is converted into steel, mostly by the basic Bessemer process, but almost all of the steel made in the district is from Spanish ore. The Cleveland deposit is not rich enough in either phosphorus or

*I am indebted to Mr. Arthur Cooper, Managing Director of the Northeastern Steel Works, for a careful reading of this section.

manganese to give a proper iron for the basic Bessemer, and it is necessary to add other ores which are richer in these elements; consequently, most of the product goes into foundry and forge pig for use at home and abroad. The output of Middlesbrough furnaces, especially those of Bell Brothers, forms the foundation of foundry practice throughout the northern part of the Continent; it is often used alone, but is mixed with iron of lower phosphorus to make the better class of castings. On another page, in the discussion of Lincolnshire, Leicestershire and Northamptonshire, further remarks will be made on the lean ore deposits of England, the ore beds of

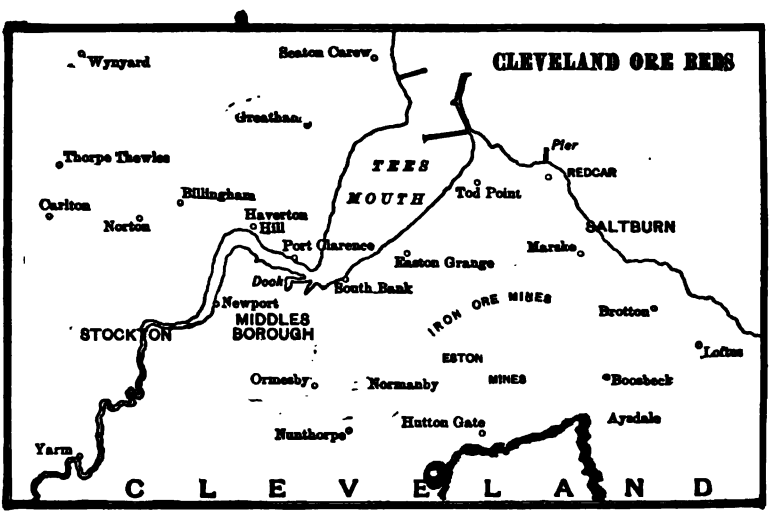


FIG. XXIII-D.

these three counties being practically of the same geological formation as the Cleveland beds. Fig. XXIII-C shows the relation of the coal field of Durham to the district around Middlesbrough, while Fig. XXIII-D shows the Cleveland ore deposits.*

The Cleveland ore is a carbonate and the composition is given by Kirchhoff as follows:

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*These maps are from letters written by C. Kirchhoff, Editor of *The Iron Age*, who has granted me permission to use them. I am indebted to the same letters for much information concerning this district.

	Per cent.
Protoxide of iron	35.37
Peroxide of iron	1.93
Protoxide of manganese	1.00
Alumina	6.95
Lime	6.63
Magnesia	3.73
Silica	10.22
Carbonic acid	22.02
Sulphur	0.10†
Phosphoric acid	1.15
Organic matter	1.20
Moisture	9.80
Total	100.10
Metallic iron	28.85
Phosphorus	0.50
Loss by calcination	29.58
Iron in calcined stone	40.96

The composition of calcined stone is given as follows:

	Per cent.
Peroxide of iron	59.77
Oxide of manganese	0.99
Alumina	9.28
Lime	9.23
Magnesia	5.41
Silica	13.66
Sulphur	0.12
Phosphoric acid	1.41
Total	99.87
Metallic iron	41.84
Phosphorus	0.62

The ore varies in different parts of the field. In many cases the content of iron is less, and there is a greater proportion of silica and earthy matter, so that a larger quantity of fuel and stone is required. For this reason considerable differences in practice and in cost will be found between furnaces in Middlesbrough. The ore deposit, at its northern edge, sometimes contains as much as 32 per cent. of iron, and in exceptional cases 33 per cent. The thickness of the bed is also greatest at this point, measuring 15 feet 7 inches at the mines of Bolckow, Vaughan & Co. Toward the south it grows thinner, the quality falls, and at the outcrop at Whitby there is only 25 per cent. of metallic iron.

The ore is calcined to expel carbonic acid, and this removes the water and organic matter, so that the roasted product contains

† I believe the average content of sulphur is nearer 0.25.

about 40 per cent. of iron. The fuel consumption in the kiln is about 80 pounds of small coal per ton of ore. The figures quoted give 41.84 per cent. of iron and 13.66 per cent. of silica, but I believe that the figures are rather roseate and refer to the best records rather than to the average, and that the general run of ore after calcining will carry only 40 per cent. of iron with silica up to 19 per cent. The average selling price from 1870 to 1883 is given by Bell as $1.02 per ton at the mines, with 30 cents freight, making a total of $1.32 per ton at the furnace. The value in 1899 is given in the Home Office Reports at $1.01 per ton at the mine. Counting a short haul and the cost of calcining, it can hardly be less than $1.15 per ton for a 30 per cent. ore; this is 3.83 cents per unit, and if the Cleveland pig contains 92 per cent. of iron, the cost of the ore per ton of pig will be $3.52. Kirchhoff gives the cost at the furnaces of Bolckow, Vaughan as 85 cents per ton, to which must be added the cost of calcining. For a 30 per cent. ore this means about $3 per ton of pig-iron. The distance from South Durham to Middlesbrough is from 20 to 30 miles, and the freight 50 cents per ton.

The coal from Durham varies, but the coals are often mixed. The average of four samples quoted by Bell is as follows:

	Per cent.
C	80.51
H	4.49
O+N	8.03
S	1.26
Ash	5.16
Water	1.01
	100.46

The fixed carbon was 70.32 per cent. and the loss in coking is over 40 per cent. in beehive ovens. The greater quantity of Durham coke is made in this type of oven, although works in Middlesbrough are introducing the by-product process. Bell states that the coke runs 6.60 per cent. in ash and 0.96 per cent. in sulphur. Kirchhoff gives the composition of four samples, averaging as follows:

	Per cent.
Carbon	88.16
Sulphur	1.11
Ash	9.33
Water	1.40
	100.00

The coke is strong and is in demand abroad, considerable quantities being exported. Two-thirds of all the coke sent abroad by England in 1903 was shipped from the Northeast Coast. There were also heavy shipments of coal, the proportion being one-third of the total exports. The ash in Durham coke is low, and this decreases the amount of silicious material entering the blast furnace. The fuel needed for a ton of Cleveland iron is given by Bell as 1⅛ tons, and in exceptional cases it may be lower, but, from information received from most excellent authority, I believe this is more often the hope than the actuality. Taking the whole campaign of the furnace and considering the amount actually paid for on board cars, there are few furnaces at Middlesbrough getting along with less than 1¼ tons, and many using more. The cost of coke is given by Kirchhoff as $1.82 to $2.20 per ton at the mines, and the cost at the furnaces at Middlesbrough will be from $2.30 to $2.70 per ton. The selling price is from $3.15 to $3.50 per ton.

When smelting Cleveland stone, the amount of limestone varies with the character of the ore. Bell gives the amount as 1175 to 1350 pounds per ton and the cost as 80 cents per ton at the furnace, so that the cost of stone would be from 43 to 49 cents per ton of iron. Kirchhoff gives 1300 pounds of stone per ton of iron, but puts the stone at $1.20 per ton, making an item of 70 cents per ton. My own information agrees with the amount above given, but Cochrane, in a detailed investigation of Cleveland practice and the use of lime, shows a consumption of 1600 pounds. In this case, however, the ore contained only 26.9 per cent. of iron. From another source I have been given the figure of 1900 pounds of stone at a cost of $1.10 per ton of stone, representing 95 cents per ton of pig-iron. We may, therefore, estimate the cost of Cleveland pig-iron for those who own their own coal mines and ore beds, counting nothing for the money invested, and also the cost for those who do not own their own supplies.

Per ton Pig-Iron.	Minimum. Complete. ownership.	Fair practice. Market prices.
Fuel 1⅛ tons @2.40	$2.70	
" 1¼ tons @3.30		$4.10
Stone 1300 lbs.	.70	.95
Ore	3.00	3.50
	$6.40	$8.55

If we add 60 cents for labor and 25 cents for supplies, which are figures given by Kirchhoff, we have a total of $7.25 for the best managed and equipped plants owning their coal and ore mines, and $9.40 for plants buying their raw material and using more fuel. Some works show a higher cost. These totals do not include general expenses and administration, nor the interest and depreciation account, so that they by no means represent the cost of pig-iron in Cleveland. They may, however, be compared with similar calculations where the cost of pig-iron in different localities is confidently predicted, as in such cases these latter items are always ignored. It may be pertinent to record that the selling price of Cleveland iron in 1900-01 was $11.20 per ton.

Thus Cleveland iron can be made cheaply, but it is an undesirable metal. It contains so much phosphorus that it is hard to use in a basic open-hearth furnace, although it is certain that it can be so used. On the other hand, it contains so little phosphorus that it is not well fitted for the basic Bessemer. For the basic converter it has been customary to enrich the phosphorus content by adding puddle cinder, and to raise the manganese by manganiferous imported ores. With the diminution of the supply of puddle cinder it is necessary to use basic converter slag in the blast furnaces, and no matter what the mixture may be, the silicon must be kept low, thus requiring a large amount of lime to flux the high silica in the ore. Taking everything together, the cost of making iron for the basic converter is given by Kirchhoff at from $1 to $1.50 per ton above the ordinary product. For open-hearth work the manganese is not necessary and the phosphorus an injury. It would seem, therefore, as if a cheap iron could be made for this purpose, while the phosphorus might be lessened by mixing with foreign ores.

The price of Spanish ore in the winter of 1900-01 was about $2.61 at Bilbao, with the low ocean freight of $1.03, making a total of $3.64 per ton at Middlesbrough. As the ore contains about 49 per cent. of iron, this gives 7.43 cents per unit, or about $7.06 per ton of iron. The assumption that the ore contains only 49 per cent. of iron may seem pessimistic, but the decrease in the quality of the Spanish ores has been a serious matter. This subject was discussed in the presidential address of William Whitwell before the Iron and Steel Institute, and he gave the composition of Rubio

ores as imported at Middlesbrough in 1890 and 1900. The comparison is as follows:

	1890	1900
Fe dry	55.50	52.80
Water	9.00	9.10
Fe as received	50.50	47.99
Silica	7.10	10.09

The ocean freight is usually 30 cents higher than the figures just given, which would make the ore cost $3.94 per ton, or about $7.60 per ton of iron. The silica runs about one-half as high as in the Cleveland stone, and the limestone needed is less, and the fuel will be about 0.95 tons per ton of pig-iron. The cost, therefore, of the ore, fuel and stone for a ton of hematite pig-iron will be as follows:

	Low freight.	Usual freight.
Ore	$7.06	$7.60
Coke	2.66	2.66
Stone (about)	.50	.50
	$10.22	$10.76

Adding the same amount for labor and supplies as in the case of Cleveland iron, viz., 85 cents, the cost of hematite iron is from $11.10 to $11.60, not reckoning general expense or interest. In the winter of 1900-01 the selling price was about $13.85 per ton.

TABLE XXIII-F.

Iron and Steel Plants on the Northeast Coast.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Bolckow, Vaughn & Co.	Middlesbro'	30	4	6	10	.....
Northeastern Steel Co.	"	4	.....	4	.....	.....
Consett Iron Co.	Durham	7	.....	.....	27	.....
Britannia and West Marsh	Middlesbro'	.....	.....	.....	11	.....
Tudhoe	Spennymoor	.....	.....	.....	10	.....
Palmer's Shipbuilding Co.	Jarrow on Tyne	5	.....	.....	8	.....
South Durham Co., 3 Works	.....	.....	.....	.....	23	.....
Armstrong, Whitworth & Co. (Elswick)	Newcastle	.....	.....	.....	6	2
Bell Brothers (Clarence)	.....	12	.....	.....	.....	6
Darlington Forge	.....	.....	.....	.....	4	.....
Sir B. Samuelson & Co.	.....	8	.....	.....	.....	.....
Edw. Williams	.....	6	.....	.....	.....	.....
Others	.....	51	.....	.....	8	.....
Total	.....	123	4	10	107	8

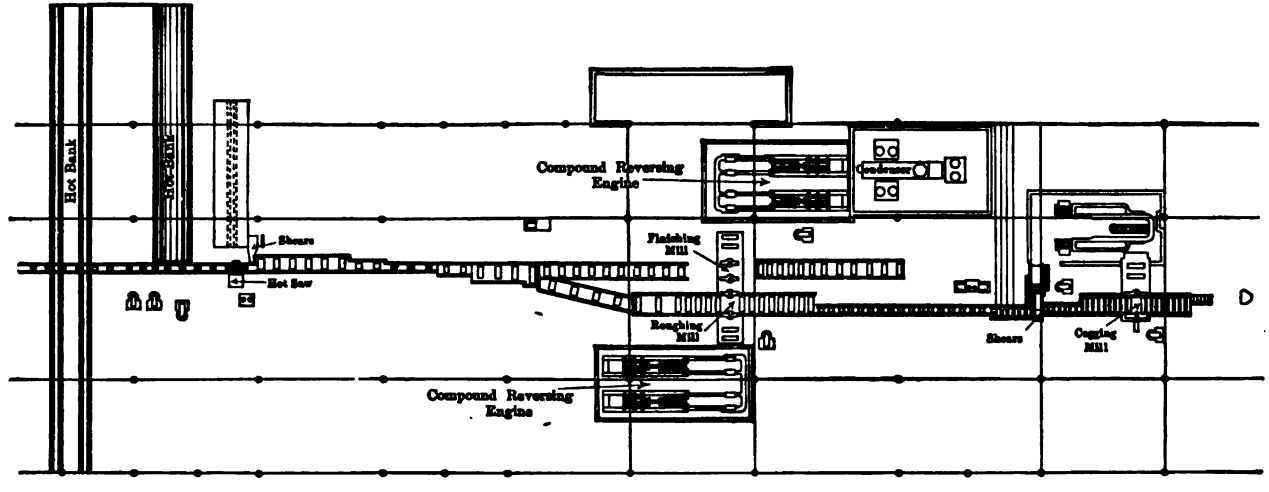


FIG. XXIII-E.—WORKS OF THE NORTHEASTERN STEEL CO., LIM., AT MIDDLESBROUGH.

The important steel works on the Northeast Coast are given in Table XXIII-F. Bell Brothers have not been large producers of steel in the past, but have lately put in an extensive open-hearth plant. Fig. XXIII-E shows a plan of the works of the North-eastern Steel Company, at Middlesbrough. In Tables XXIII-G and H are given data concerning the industrial history of the district.

TABLE XXIII-G.

Output of Ore and Pig-Iron on the Northeast Coast.

Average for Period per year.	Ore Raised; Tons.			Pig Iron; Tons.		
	North Yorkshire.	Durham	Total.	North Yorkshire.	Durham & Northumberland.	Total.
1882 to 1885 incl.....	6,266,805	55,710	6,322,516	1,786,064	832,607	2,618,671
1886 to 1890 incl.....	5,404,267	11,995	5,416,262	1,861,996	780,461	2,642,457
1891 to 1895 incl.....	4,699,961	7,747	4,707,708	1,838,626	799,308	2,637,934
1896 to 1900 incl.....	5,638,882	18,601	5,657,482	2,157,304	1,026,533	3,193,837
1901 to 1905 incl.....	5,393,590	18,051	5,411,621	1,966,853	996,158	2,963,011

TABLE XXIII-H.

Imports of Ore at Ports on the Northeast Coast.

Average for Period per year; tons.	Middlesbro.	No. & So. Shields & Newcastle	Stockton.	Hartlepool.	Sunderland.	Others.	Total.
1882 to 1885 incl.	434,000	294,000	76,000	41,000	67,000	8,000	920,000
1886 to 1890 incl.	969,000	493,000	144,000	155,000	93,000	6,000	1,860,000
1891 to 1895 incl.	1,413,000	544,000	231,000	115,000	97,000	.....	2,400,000
1896 to 1900 incl.	1,568,000	826,000	285,000	165,000	94,000	4,000	2,942,000
1901 to 1905 incl.	1,113,000	498,000	230,000	136,000	74,000	.....	2,051,000

SEC. XXIIIc.—*Scotland (Ayrshire and Lanarkshire):*

I am indebted to Mr. James Riley, formerly general manager of the Steel Company of Scotland and of the Glasgow Iron and Steel Company, for a careful review of this section.

The iron industry of Scotland dates back one hundred and fifty years, but it was well along in the last century before there was any appreciation of the value of the blackband from the coal measures which at that time existed throughout Ayrshire and Lanarkshire. This blackband was roasted and gave an ore making 63 per cent. of pig-iron. In 1870 Scotland produced 3,500,000 tons of ore, but in 1880 this dropped to 2,660,000 tons. Half of this was black-

band, but the price had risen to $3.60 per ton at the pit. In 1900 only 597,826 tons of ore were raised from the coal measures, the price being officially given as $2.40 per ton at the pit mouth, and this constituted 70 per cent. of all the ore raised in Scotland.

The pig-iron industry, in spite of the disappearance of the blackband and the importation of foreign ores, still retains a distinctive characteristic in the use of raw "splint" coal in the blast furnace. The composition of Lanark coal is as follows:

	Per cent.
C	66.00
H	4.34
O+N	12.03
S	0.59
Ash	5.42
Water	11.62
	100.00
Fixed carbon	53.4

This coal, when charged into the furnace, will not fuse and get sticky, provided the furnace is not more than 70 feet high. The heating value is only 80 per cent. of Durham coal, but counting the loss in the coking process, there is a slight advantage, ton for ton, in the Scotch coal charged in the furnace over the Durham coal, which must first be coked. When using this raw coal the furnace gases contain a quantity of hydrocarbons, and it is profitable to put up scrubbers and collect the tar and ammonia before the gas passes to the boilers and stoves. The best beds of Lanarkshire coal are approaching exhaustion, and recently some plants have experimented in the making of a poor coke from local coal and using it as a mixture with the inferior splint coals, but this practice seems to make no progress. A considerable amount of coke is

TABLE XXIII-I.

Production of Pig-Iron in Scotland.

Period. Inclusive.	Production per year. Tons.
1861 to 1865	1,122,600
1866 to 1870	1,089,800
1871 to 1875	1,021,600
1876 to 1880	993,600
1881 to 1885	1,084,400
1886 to 1890	922,217
1891 to 1895	826,128
1896 to 1900	1,128,161
1901 to 1903	1,282,967

made in the Kilsyth district, for foundry purposes. The district of Ayrshire and Lanarkshire produces 9 per cent. of all the coal raised in the Kingdom, and exports large quantities. In spite of the great decrease in the supply of native ore, the production of pig-iron has been sustained by the use of Spanish ores, but there has been little increase, the amount smelted having remained nearly constant during the last forty years, as shown in Table XXIII-I.

Scotland now makes 14 per cent. of the pig-iron and 18 per cent. of the steel made in the Kingdom. Most of the ore is imported from Spain, and the pig-iron is used to make acid open-hearth steel for shipbuilding and other purposes. Scotland makes only a small

TABLE XXIII-J.

Iron and Steel Plants in Scotland (Ayrshire and Lanarkshire).

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.	Open Hearth Furnaces.	
			Basic.	Acid.	Basic.
Steel Co. of Scotland.....	Newton .... Glasgow....	.....	.....	30	1
David Colville & Sons (Dalzell).....	Motherwell..	.....	.....	18	.....
Parkhead Forge.....	Glasgow.....	.....	.....	6	.....
Glasgow I. and S. Co.....	Wishaw.....	4	.....	12	.....
Lanarkshire.....	Flemington..	.....	.....	8	.....
Glengarnock.....	Ayrshire.....	12	4-10 tons	3	.....
Clydebridge.....	Cambuslang.	.....	.....	9	.....
Clydesdale.....	Mossend.....	.....	.....	9	.....
Summerlee & Mossend Co.	Mossend.....	7	.....	8	.....
Other open hearth plants..	.....	.....	.....	8	.....
Wm. Baird & Co.....	Scattered	26	.....	.....	.....
Coltness Iron Co.....	Coltness	9	.....	.....	.....
Wm. Dixon.....	Scattered...	11	.....	.....	.....
Others.....	.....	26	.....	.....	.....
Total.....	.....	95	4	111	1

amount of Bessemer steel and hardly any basic open-hearth, but she makes more acid open-hearth steel than Cleveland, each of them making one-third of all that kind of metal made in Great Britain. Table XXIII-J gives a list of the principal plants in Scotland. Most of the steel plants make plates and miscellaneous structural bars. In Tables XXIII-K and L are given certain items of statistical information; the importations of ore come mostly to ports on the western shore, but a considerable quantity is brought to the Firth of Forth.

TABLE XXIII-K.

Output of Ore and Pig-Iron in Scotland.

Average for period per year; tons.	Ore Raised.	Pig Iron.		
		Ayrshire.	Lanarkshire.	Total.
1882 to 1885 inclusive.....	2,088,652	333,516	728,125	1,061,641
1886 to 1890 inclusive.....	1,225,559	296,998	625,218	922,216
1891 to 1895 inclusive.....	784,831	246,758	579,370	826,128
1896 to 1900 inclusive.....	887,471	353,274	774,887	1,128,161
1901 to 1903 inclusive.....	811,260	365,599	867,369	1,232,968

TABLE XXIII-L.

Imports of Iron Ore at Ports in Scotland.

Average for period per year; tons.	Glasgow.	Ardrossen.	Ayr.	Troon.	Others.	Total.
1882 to 1885 inclusive.....	272,000	34,000	14,000	6,000	83,000	409,000
1886 to 1890 inclusive.....	312,000	33,000	42,000	10,000	178,000	575,000
1891 to 1895 inclusive.....	387,000	141,000	54,000	32,000	81,000	695,000
1896 to 1900 inclusive.....	680,000	422,000	110,000	84,000	98,000	1,394,000
1901 to 1903 inclusive.....	877,000	413,000	99,000	116,000	135,000	1,640,000

SEC. XXIIId.—*South Wales:*

In this district I have included Glamorganshire and the English county of Monmouth. Near by in Gloucestershire is the Forest of Dean, once famous as an iron district, but which, in 1900, produced only 9885 tons of ore, no pig-iron being made in its borders. The iron industry of South Wales was founded on a lean clay band running 30 per cent. in iron. In 1860 the above-mentioned counties raised 830,000 tons of ore and in 1870 the amount was a trifle larger. From then the production decreased, being only half as much in 1880, while now it is a negligible quantity. The production of pig-iron has remained stationary from 1860 until now. Before the local ores failed the hematites of the West Coast were brought in, and then by providential dispensation the mines of northern Spain were developed, and from that time South Wales has run exclusively on this imported supply.

In former times the coal from certain districts at works near Merthyr was used directly in the furnace in the same way as in Scotland, but this practice has been discarded and a richer coal is

now coked. The volatile matter in this coal is low, running from 16 to 22 per cent., and some seams contain 30 per cent. of ash, but,

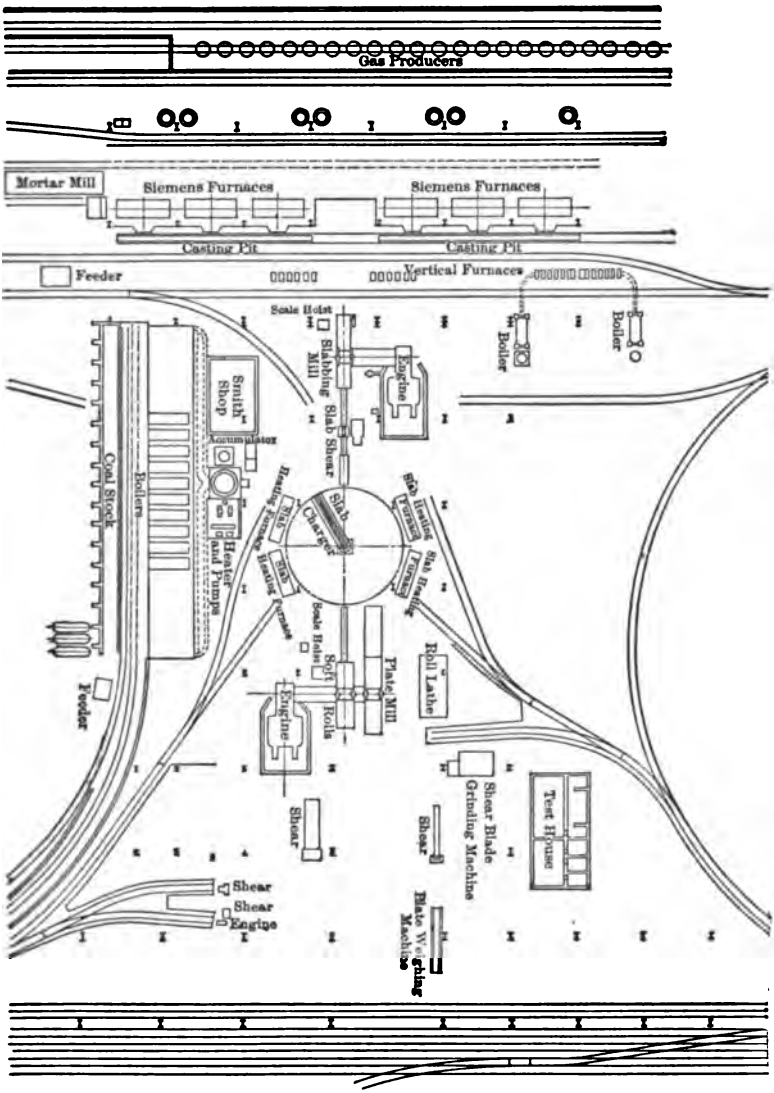


FIG. XXIII-F.—DOWLAIS WORKS, CARDIFF, WALES.

by washing, this may be reduced so that the coke contains only 10 per cent. and good results are obtained. The Spanish hematites im-

ported at Cardiff in 1899 contained only 50 per cent. of iron and from 7 to 14 per cent. of silica, but they were smelted with one ton of coke per ton of iron. Some of the older iron works are in the interior, a legacy from ancient times, but new plants are on tide-water, thus reducing the freight on both raw material and finished product.

The northern shore of the Bristol Channel produced almost exactly the same quantity of steel in 1903 as Scotland. Unlike Scotland, half of the output is Bessemer; but like Scotland, it is all acid, both Bessemer and open-hearth. This district in 1903 raised 18 per cent. of all the coal mined in the island and furnished 44 per cent. of all the coal exported from the Kingdom,

TABLE XXIII-M.

Iron and Steel Plants in Glamorganshire, Monmouthshire and Gloucestershire.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Blaenavon Co.	Blaenavon	9	2	.....	2	.....
Crawshay Bros. (Cyfarthfa)	Merthyr Tydfil	9	4	.....	.....	.....
Ebbw Vale S. and I. Co.	Ebbw Vale	6	6	.....	2	.....
Guest Keen & Co., formerly Dowlais Iron Co.	Dowlais Cardiff	19	6	.....	8 6	.....
Nettlefolds	Newport	.....	2	.....	.....	.....
Tredegar	Tredegar	5	2	.....	.....	.....
Elba & Panteg	Swansea	.....	.....	.....	8	.....
Swansea Hem. I. & S. Wks.	Landore	2	.....	.....	5	.....
Briton Ferry	Briton Ferry	2	.....	.....	6	.....
Pontardawe Steel Works	.....	.....	.....	.....	5	.....
Upper Forest	Morriston	.....	.....	.....	5	.....
Other open hearth plants	.....	.....	.....	.....	37	.....
Rhymney Iron Co.	.....	9	.....	.....	.....	.....
Other blast furnace plants	.....	8	.....	.....	.....	.....
Total	.....	69	.....	.....	84	.....

and 14 per cent. of all the export coke. It made about 10 per cent. of all the pig-iron and 21 per cent. of all the steel. The make of puddled iron is small. This arises from the fact that there are no cheap native ores and it does not pay to put iron from Spanish ores into puddled bar.

Fig. XXIII-F shows a ground plan of the new open-hearth plant and plate mill of the Dowlais Iron Company at Cardiff, this being one of the best arranged plants in Great Britain. Table XXIII-M

TABLE XXIII-N.

Production of Pig Iron in South Wales and Monmouthshire.

Average for period per year; tons.	Glamorganshire.	Monmouthshire.	Total.
1882 to 1885 inclusive	380,361	490,857	871,218
1886 to 1890 inclusive	369,447	421,772	791,219
1891 to 1895 inclusive	438,333	269,386	707,719
1896 to 1900 inclusive	479,361*	294,256*	773,617
1901 to 1908 inclusive	521,058*	220,908*	741,966

*The Home Office Reports, beginning in 1900, combines North and South Wales. I have assumed that Denbigh, in North Wales, makes 20,000 tons of pig iron per year, and Flint 30,000 tons.

TABLE XXIII-O.

Imports of Ore on the Bristol Channel.

Average for period per year; tons.	Cardiff.	Newport.	Swansea.	Others.	Total.
1882 to 1885 inclusive	544,000	697,000	153,000	1,000	1,395,000
1886 to 1890 inclusive	523,000	693,000	123,000	4,000	1,343,000
1891 to 1895 inclusive	601,000	430,000	150,000	2,000	1,183,000
1896 to 1900 inclusive	693,000	475,000	218,000	1,000	1,388,000
1901 to 1908 inclusive	769,000	316,000	169,000	3,000	1,257,000

gives the principal plants in the district, and Tables XXIII-N and O give certain statistics.

SEC. XXIIIe.—*Lancashire and Cumberland:*

I am indebted to Mr. J. M. While, general manager of the Barrow Works, for reading the manuscript relating to this district.

The county of Lancaster reaches across Morecambe Bay and includes Barrow-in-Furness and the Barrow Steel Works. It is in this detached portion of Lancashire and the neighboring portion of Cumberland that all the ore is raised and a great part of the iron and steel made. It is the custom, however, to keep the records by geographical lines, and the output of Barrow-in-Furness is combined with the output of South Lancashire and sometimes with that of Derby. This last named county produces no ore, but its output of both coal and pig-iron is two-thirds as much as Lancashire.

The especial feature of Cumberland and northwest Lancashire is the deposit of what are known as West Coast hematites. Up to 1830 these beds were little known and no pig-iron was smelted in either Cumberland or Lancashire. In 1854 the production of ore

was 579,000 tons, but this was sent to South Wales and South Staffordshire. In 1860 the output had increased to 990,000, in 1870 it was 2,093,000, and in 1882 it reached 3,136,000 tons. With this great development of the ore beds, blast furnaces sprang up both in Cumberland and northwest Lancashire, and in 1860 there were 169,000 tons of pig-iron smelted. In 1870 this had increased to 678,000 tons, while in 1882 the record was 1,792,000 tons.

The imports of ore on the West Coast at that time averaged about 300,000 tons per year, but these were manganiferous ores and were used in making spiegel. In the early eighties the West Coast hematites played an important part in the international iron industry. A large quantity of the pig-iron was exported, much of it to America, its low phosphorus content rendering it especially valuable for acid Bessemer work. That day has passed away, and the deposits are thinning out. In 1903 there were only 1,490,549 tons of ore mined, or less than half the output in 1882.

The ore now produced may be roughly divided into two classes, the output of the famous Hodbarrow mine constituting a class by itself.

	Hodbarrow.	Other Mines.
Fe, per cent	59	49
P, per cent		.01
SiO_2, per cent	6.0	18
Price per ton at mines in 1899	4.86	3.72
Price per ton at mines in 1900	5.60	4.25
Price per unit at mines in 1899	8.24	7.6
Price per unit at mines in 1900	9.5	8.68

Many of the mines are exhausted, while others spend large sums of money in exploration. The supply at one mine has been prolonged by building a sea-wall through an arm of a bay and pumping the pond dry. The success of this undertaking led to a larger project along the same line, when the newly won territory showed signs of exhaustion. The pig-iron production of this district has been maintained by the importation of Spanish ores, the output having remained nearly constant for twenty years. Some of the coke is brought from Durham, which is 111 miles from Barrow, with a freight rate of $1.22 per gross ton, and some from West Yorkshire, a distance of 117 miles from Barrow, the freight being $1.32 per ton.

Lancaster and Cumberland in the year 1903 produced 26,724,480 tons of coal, or 12 per cent. of the total, almost all from Lancashire. The production of pig-iron was 1,485,785 tons, or 17 per cent. of the

TABLE XXIII-P.

Iron and Steel Plants in Cumberland and Lancashire.

Name of Works.	Location	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Barrow Hem. S. Co.....	Barrow in Furness.	12	4	.....	7	.....
London & Northwestern.....	Crewe.....	.....	4	.....	10	.....
Moss Bay.....	Workington.....	4	3	.....	1	.....
Cammell, Laird & Co..	Workington.....	.....	10	.....	.....	.....
Bolton I. & S. Co.....	Bolton	.....	.....	.....	5	.....
Wigan C. & I. Co.....	Wigan	10	.....	.....	.....	6
Salford	Manchester,.....	.....	.....	.....	2	.....
Millom & Askam Co...	Askham	9	.....	.....	.....	.....
Carnforth Hem. I. & S. Co.....	.....	4	.....	.....	.....	.....
North Lonsdale I. & S. Co.....	.....	4	.....	.....	.....	.....
Cammell & Co.....	Derwent.....	8	.....	.....	.....	.....
	Solway.....					
Northwestern H. I. & S. Co.....	.....	5	.....	.....	.....	.....
Others.....	.....	25	.....	.....	.....	.....
Total.....	.....	81	21	.....	25	6

total, while the steel constituted 16 per cent. of the outturn of the Kingdom. There were also produced 132,588 tons of puddled bar, being 14 per cent. of the total output. Almost all this was made in Lancashire.

The principal plants are given in Table XXIII-P, the Barrow Works being in northwest Lancashire, in Barrow-in-Furness, and

TABLE XXIII-Q.

Output of Ore and Pig-Iron on the West Coast.

Average for period per year; tons.	Ore Raised.			Pig Iron.		
	Cumberland.	Lancashire.	Total.	Cumberland.	Lancashire.	Total.
1882 to 1885 incl....	1,447,678	1,307,547	2,755,225	747,728	854,834	1,602,562
1886 to 1890 incl....	1,468,326	1,101,026	2,569,352	739,001	849,554	1,588,555
1891 to 1895 incl....	1,325,455	873,628	2,199,083	608,060	676,153	1,284,183
1896 to 1900 incl....	1,213,332	730,142	1,943,474	718,577	857,718	1,576,295
1901 to 1903 incl....	1,068,219	471,564	1,539,783	816,694	669,462	1,486 156

the other large works in Cumberland. The furnaces of Millom and Askam Company make iron for the open market, and one of them, started in August, 1901, is built on modern American lines. Tables XXIII-Q and R give statistics concerning this district. The imports at Chester, Liverpool and Manchester are grouped sepa-

TABLE XXIII-R.

Imports of Ore at Ports on the West Coast.

Average for period per year; tons.	Barrow.	Maryport.	Workington.	Chester, Liverpool and Manchester.	Others.	Total.
1882 to 1885 incl....	10,000	15,000	36,000	126,000	90,000	277,000
1886 to 1890 incl....	34,000	122,000	23,000	112,000	26,000	317,000
1891 to 1895 incl....	30,000	62,000	3,000	64,000	6,000	165,000
1896 to 1900 incl....	247,000	386,000	113,000	81,000	55,000	882,000
1901 to 1903 incl....	322,000	455,000	152,000	87,000	108 000	1,124,000

rately, as these ports supply a different region from the northern points. A considerable proportion of the imports at these more southern harbors goes to furnaces outside of Lancashire.

SEC. XXIIIf.—*South Yorkshire:*

The district of South and West Yorkshire includes the historic works of Bradford, Leeds and Sheffield. It has never been a great

TABLE XXIII-S.

Iron and Steel Plants in South Yorkshire.

Name of Works.	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Brown, Bayley & Co., Attercliffe.	Sheffield..	.....	2	.....	4	.....
Bessemer, H., & Co., Bessemer..	" ..	.....	2	.....	2	.....
Fox, Samuel, & Co.....	" ..	.....	2	.....	.....	.....
Steel, Peach & Tozer, Phœnix..	" ..	.....	2	.....	3	.....
Cammell, Laird & Co.....	" ..	.....	.....	.....	6	.....
Cammell, Laird & Co.....	Penistone.	.....	4	.....	.....	.....
Scott, Walter, Leeds Steel Wks.	Leeds.....	3	.....	4	.....	.....
Parkgate Iron Co.....	Sheffield..	5	.....	.....	1	5
Brown, J., & Co., Atlas.....	" ..	3	.....	.....	5	.....
Firth & Sons, Norfolk.....	" ..	.....	.....	.....	4	.....
Vickers, Sons & Maxim.....	" ..	.....	.....	.....	4	.....
Hadfield St. Fdy Co.....	" ..	.....	.....	.....	3	.....
Others.....	.....	.....	.....	.....	7	.....
W. Yorkshire Iron and Coal Co.	.....	5	.....	.....	.....	.....
Lowmoor Co,.....	.....	4	.....	.....	.....	.....
Others.....	.....	6	.....	.....	.....	.....
Total.....	.....	26	.....	.....	39	5

producer of iron ore or of pig-iron, but Sheffield was known five hundred years ago as a maker of steel, and it was here that the crucible process had its birth. The present importance of the district comes from the old established works and the subsidiary steel-using establishments and finishing mills that have grown up around some of the landmarks of the iron trade.

This district makes about 280,000 tons of pig-iron per year, or 3 per cent. of the total output; it makes 550,000 tons of steel, this being 12 per cent. of the total of the Kingdom. It also makes 125,000 tons of puddled bar, or 13 per cent. of the total. The principal

TABLE XXIII-T.

Output of Pig-Iron in South Yorkshire (Sheffield).

Period.	Average per Yaer; Tons.
1882 to 1885 inclusive.....	259,995
1886 to 1890 inclusive.....	196,844
1891 to 1895 inclusive.....	213,045
1896 to 1900 inclusive.....	295,608
1901 to 1908 inclusive.....	276,491

steel works in the district are shown in Table XXIII-S, and the yearly output of pig-iron in Table XXIII-T.

SEC. XXIIIg.—*Staffordshire:*

It is customary to divide this county into a northern and southern portion. Forty years ago the south produced more ore than the north and three times as much pig-iron. The ore was a poor ironstone imbedded in the shale of the coal formations, but the deposit has slowly become exhausted and it is necessary to excavate so much shale that the selected ore is expensive. For these reasons the mining of ore has almost ceased in this southern portion and the furnaces run on hematite from Lancashire or Spain, blackband from North Staffordshire, or the cheap but silicious ores of Northamptonshire, which need be hauled only 60 miles.

In North Staffordshire the ore consists mainly of blackband. Bell gives the details of the occurrence in one mine as follows:

(1) Blackband 14 inches thick lying on the top of 18 inches of poor coal.

(2) "Red slag ironstone" 16 inches thick lying above 2 feet of poor coal.

(3) "Red mine stone" 20 inches thick with 18 inches of coal.

There is also a bed of clay ironstone 3½ feet in thickness. The yield of pig-iron from the calcined blackband is 50 per cent. The amount raised is 750,000 tons per year, so that this deposit is of no small economic interest.

The whole county in 1903 produced 13,037,553 tons of coal, or 6 per cent. of the total output; 738,549 tons of ore, or 6 per cent. of the total, almost all being in the northern portion; 585,330 tons of pig-iron or 7 per cent. of the total, and 392,737 tons of steel, or 8 per cent. of the total.

The county also made 306,000 tons of puddled bar, which is one-third of the entire output of Great Britain. Two-thirds of this is made in South Staffordshire. This is the only district in Great Britain where the puddling industry is holding its own.

Table XXIII-U gives the annual output of ore and pig-iron.

TABLE XXIII-U.

Output of Ore and Pig-Iron in North and South Staffordshire.

Average for period per year; tons.	Ore Raised.			Pig Iron.		
	North.	South.	Total.	North.	South.	Total.
1882 to 1885 inclusive.....	1,774,205	106,567	1,880,772	277,167	272,292	549,459
1886 to 1890 inclusive.....	1,272,784	68,422	1,341,206	260,973	281,090	542,063
1891 to 1895 inclusive.....	885,922	39,501	925,423	215,279	290,651	505,930
1896 to 1900 inclusive.....	982,733	42,115	1,024,848	260,610	325,572	586,182
1901 to 1908 inclusive.....	757,173	36,125	793,298	239,995	316,467	556,462

SEC. XXIIIh.—*The Eastern Central District; Lincoln, Leicester and Northampton; and the Central District; Derby and Nottingham:*

The eastern shore of England, just south of the Humber, is not usually regarded as one of the great iron centers of the world, but it is of considerable consequence. Lincoln, Leicester and Northampton in 1903 produced one-third of all the ore raised in Great Britain, and made more pig-iron than Staffordshire.

The ore of Lincolnshire is an oolite, occurring in a bed from ten to twenty feet thick, and is easily mined. It is only two or three feet below the surface and is worked in open quarry. Bell gives the composition for each foot in depth for eight successive feet, stating that the results are typical. In the wet state the iron was

from 21 to 37 per cent., and in the dry state from 21 to 45 per cent. The ore is sorted by hand-and-eye inspection, and the average product in a dry state carries 34 per cent. of iron with 6 per cent. of silica and 28 per cent. of carbonic acid and lime, the latter making the ore self-fluxing. It is even a little too calcareous and needs mixing with a silicious ore. Its value is given as 75 cents at the mines. The ore was once a carbonate, but by exposure has changed to a hydrated peroxide and is used without calcining. Northampton raises an increasing amount of a lean and silicious iron ore, some of which is smelted near by, and the rest sent to Staffordshire and elsewhere. The ore gives 38 per cent. in the pig-iron, and is worked in the open from a bed 18 feet thick. After paying royalty the ore can be delivered at near-by furnaces for 65 cents per ton. This gives a cost of $1.70 for the ore per ton of pig-iron, but the high silica renders the smelting costly.

The deposits in this part of England are related geologically to the Cleveland beds and may be looked upon as the southern outcrop. The use of these lean ores is a recent development, just as in Luxemburg the Minette deposit has come only recently into prominence. In 1830 there were only 5300 tons of iron made from the lean ores of Cleveland and Lincolnshire. In 1860 Cleveland mined 1,480,000 tons of ore, and by 1870 this had risen to 4,300,000 tons, and by 1880 to 6,260,000 tons. The increase has not continued in

TABLE XXIII-V.

Output of Ore and Pig-Iron in Eastern Central England.

Average for period per year; tons.	Ore Raised.				Pig Iron.		
	Leicester.	Lincoln.	Northampton.	Total.	Lincoln and Leicester.	Northampton.	Total.
1882 to 1885 inclusive.	283,748	1,233,075	1,265,739	2,782,562	233,352	198,807	432,159
1886 to 1890 inclusive.	498,423	1,291,550	1,106,824	2,896,797	279,493	225,390	504,483
1891 to 1895 inclusive.	592,957	1,364,279	1,019,200	2,976,436	294,749	198,824	493,573
1896 to 1900 inclusive.	708,377	1,841,955	1,467,393	4,017,725	380,815	260,466	641,281
1901 to 1903 inclusive.	676,738	1,747,209	1,705,900	4,129,847	364,785	235,639	600,424

Cleveland, which in 1903 mined only 5,677,560 tons, but the mines of the southern district are coming to the front. In 1860 this region raised only 118,000 tons; in 1870, 1,048,000 tons; in 1880, 2,766,000 tons; while in 1903 the output of the three counties of

TABLE XXIII-W.

Output of Pig-Iron in Central England.

Average for period per year; tons.	Derbyshire and Nottingham.
1882 to 1885 inclusive	437,354
1886 to 1890 inclusive	387,794
1891 to 1895 inclusive	417,139
1896 to 1900 inclusive	521,357
1901 to 1908 inclusive	507,825

Lincoln, Leicester and Northampton reached 4,479,578 tons. Thus, although the production of the Cleveland district has fallen since 1880, the total production of the lean ores from this geological horizon has increased from 9,026,000 to 10,157,138 tons. Estimating the average iron content of the ore at 32 per cent. and the iron in the pig at 93 per cent., this amount of ore represents about 3,500,000 tons of pig-iron, or about 40 per cent. of the total pig-iron made in the kingdom. Tables XXIII-V and W give statistics on the iron industry of this district.

CHAPTER XXIV.

GERMANY.

In discussing the German iron industry I have been guided mainly by personal knowledge of the different districts. There were also at hand a series of letters by Kirchhoff in *The Iron Age*, May, 1900. The data on steel works, blast furnaces and puddling furnaces are taken from the *Gemeinfassliche Darstellung des Eisenhüttenwesens*, and the boundaries of the districts are reproduced from drawings and descriptions made out for me by Dr. Wedding, of Berlin. The manuscript of the first edition was submitted both to Dr. Wedding and to Herr Schrödter, editor of *Stahl und Eisen*, and since this book was published it has been read by other friends in Germany, and I am indebted particularly to Mr. Franz J. Müller, General Director of the Rheinische Steelworks at Ruhrort, and to O. von Kraewel, Superintendent of the same company, for a critical review, the information derived from them during a visit to Ruhrort being used in revising, for later editions, both this chapter on Germany and the account of the basic Bessemer process;

SECTION XXIVa.—*Statistics.*—Germany recognizes three kinds of product: (1) ingots for sale; (2) half-finished product; (3) finished product; but if one works sell ingots to another, and the second makes billets and sells them to a third mill for rerolling, then this steel is put into the total three separate times. A large amount is actually added twice, because almost all the wire mills in Germany are independent. Within the last few years the production of ingots has been collected, but before that time no statistics were

TABLE XXIV-A.

Approximate Annual Output of Ore and Pig-Iron in Germany.

	Ore.	Pig Iron.
Rhenish Westphalia	210,000	4,010,000
Lothringen	10,680,000	1,980,000
Luxemburg	6,010,000	1,230,000
Silesia	390,000	750,000
The Saar	.....	740,000
The Siegen and Lahn	3,180,000	720,000
Hanover	800,000	360,000
Other districts	750,000	300,000
Total	22,000,000	10,090,000

reliable, and even now no data are published as to the output of separate districts. I am able, however, in Table XXIV-C to present, for the first time in any publication, a reasonably accurate es-

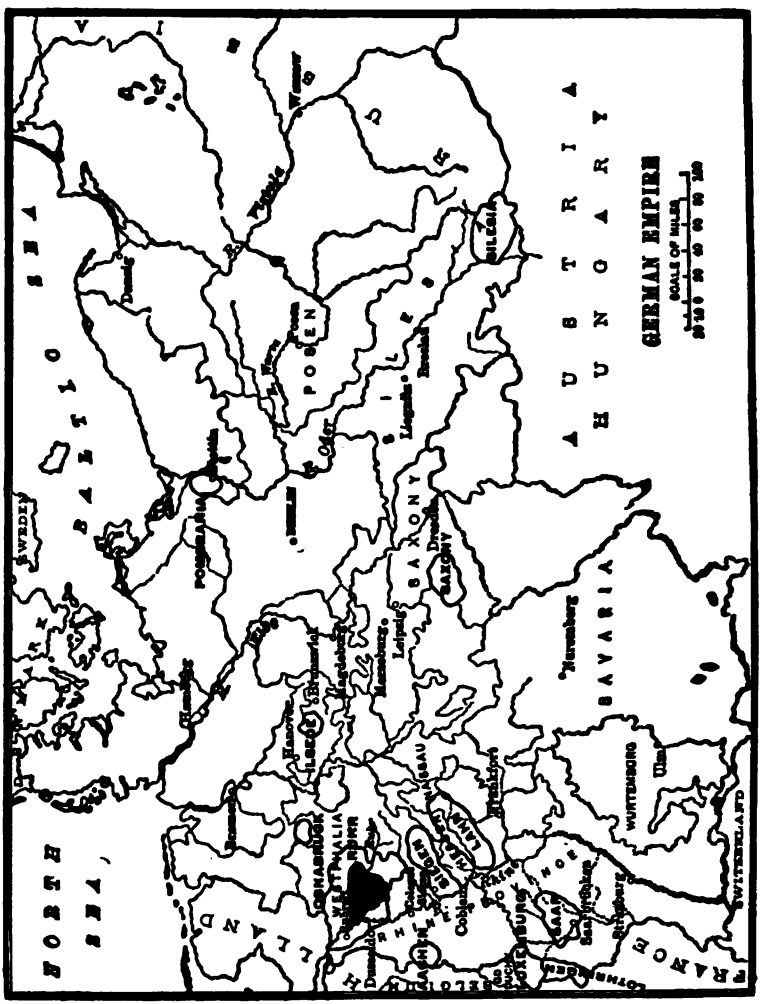


Fig. XXIV-A.

timate by high authority of the output of steel in different districts. The general statistical situation is shown in Tables XXIV-A, B and C.

TABLE XXIV-B.

Movement of Ore in Germany in the Year 1899.

District.	Lothringen and Luxemburg.	Ruhr.	Silesia.	Pomerania.
Ore raised	12,987,152	212,794	476,823	none
Exported to Belgium	1,807,421	.....	.....	.....
" France	1,271,052	.....	.....	.....
" Austria	.....	.....	33,787	.....
Imported from Spain	.....	1,984,769	.....	124,200
" " Sweden	.....	1,384,447	275,406	.....
" " Hungary	.....	.....	329,705	.....
Sent to the Saar and the Ruhr	1,337,000	.....	.....	.....
Brought from the Siegen, the Lahn and Lothringen	.....	4,734,600	.....	.....

TABLE XXIV-C.

Output of Ingots in Germany for Twelve Months, 1902-03.

District.	Acid Bessemer.	Basic Bessemer.	Acid Open Hearth.	Basic Open Hearth.	Total.
The Ruhr	240,000	2,946,000	176,000	1,667,000	4,289,000
Silesia	55,000	242,000	.....	292,000	589,000
Lothringen	.....	953,000	.....	45,000	998,000
Luxemburg	.....	408,000	.....	.....	408,000
The Saar	.....	867,000	10,000	160,000	1,037,000
Saxony	10,800	40,000	7,200	85,000	143,000
Siegerland	.....	.....	.....	154,000	154,000
Aachen	.....	297,000	.....	46,000	333,000
Ilsede-Peine	.....	239,000	.....	.....	239,000
Osnabruck	29,000	.....	.....	30,000	59,000
Bavaria	.....	100,000	.....	30,000	130,000
Total	334,800	5,382,000	193,200	2,509,000	8,419,000

SEC. XXIVb.—*Lothringen and Luxemburg:*

The province of Lothringen is the old French Lorraine. Following its incorporation into Germany, not only was its name changed, but every town received either a new name or a German prefix or suffix. This was natural, for it is impossible for German or English people to pronounce many of the French names, and it would have been absurd to have a German city called by a name that nine-tenths of the inhabitants could not pronounce. Many maps of Lothringen contain the old names, and these are used exclusively in France and Belgium, and widely in England and America, while the term Lorraine is known to a hundred Americans where Lothringen is known to one. This change, natural though it is, entails endless confusion upon the traveler, who might guess that

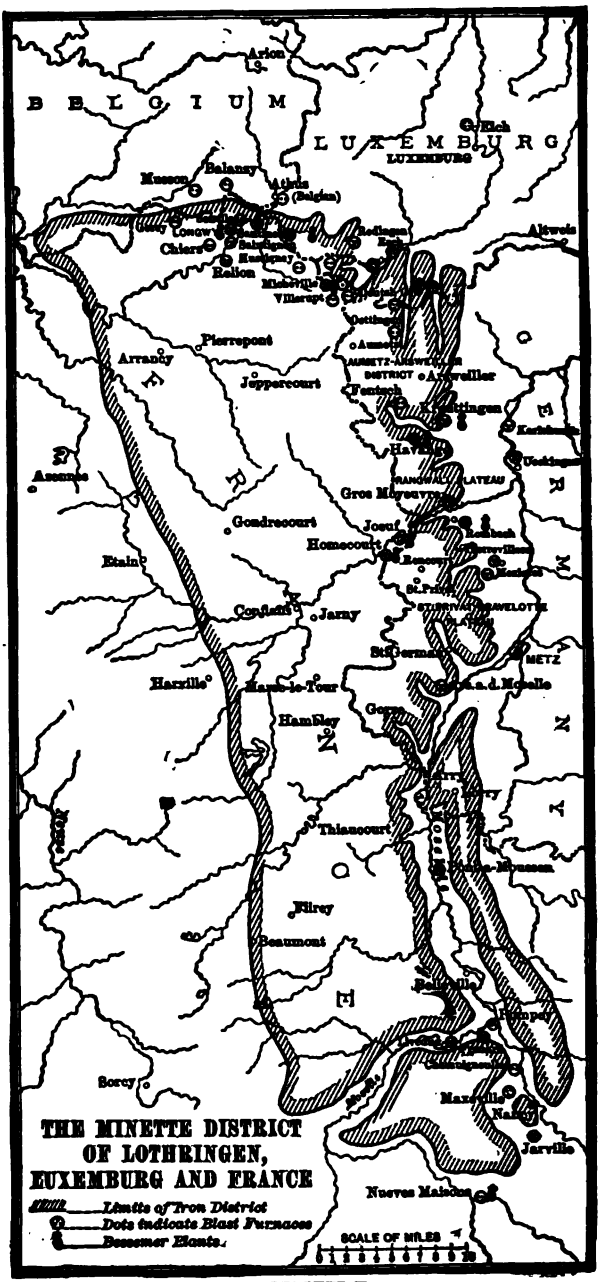

B E L G I U M
L U X E M B U R G
LUXEMBURG
Arlon
Balanzy
Messon
Chiers
Longwy
Rodange
Esch
Aiwais
Rollon
Villerupt
Pierrepont
Arrancy
Jeppercourt
Ancerville
Gravelotte
Gros Moyeuvre
Gondrecourt
Joeuf
Homecourt
Etain
Conflans
Jarny
St Germain
METZ
Harville
Mars-la-Tour
Hamlay
Thiaucourt
Flirey
Beaumont
Pont-a-Mousson
Nancy
Jarville
Sorcy
Nueves Maisons
THE MINETTE DISTRICT
OF LOTHRINGEN,
LUXEMBURG AND FRANCE
Limits of Iron District
Dots indicate Blast Furnaces
Bessemer Plants.
SCALE OF MILES

FIG. XXIV-B.

TABLE XXIV-D.

Composition of Ores from Lothringen and Luxemburg and Data showing the Thickness of the Beds, and Thickness of Intermingled Strata of Earth and Limestone, arranged from Schrödter, Stahl und Eisen, March 15, 1896. Also data from Wedding, Eisenhüttenkunde, Zweite, 1897, p. 59; Kohlmann, Stahl und Eisen, Vol. XVIII, p. 593; and Stahl und Eisen, Vol. XX, p. 1266.

Note; the boreholes are at different points in the Aumetz Arsweiler district.

Strata and Thickness in Feet.				Fe	Mn	P	SiO_2	CaO	Al_2O_3	
Schrödter Borehole	Depth from Surface	Thickness of Layer	Character of Deposit							
A	0	16	Red sand....	25.6	.....	.....	33.3	9.4	.....	.....
	16	10	Red sand....	26.6	.....	.....	31.3	9.5	.....	.....
	26	41	Lime & clay.	.....	.....	.....	.....	.....	.....	.....
	67	9	Red Minette.	30.7	.....	.....	7.5	21.5	5.7	.....
	76	1	Lime.....	.....	.....	.....	.....	.....	.....	.....
	77	1	Red Minette.	38.5	.....	.....	9.2	12.1	6.9	.....
	78	3	Red Minette.	32.4	.....	.....	10.0	19.8	5.8	.....
	81	7	Red ore.....	39.4	.....	.....	7.7	11.6	4.9	.....
	88	19	Earth.....	.....	.....	.....	.....	.....	.....	.....
	107	13	Gray ore.....	33.7	.....	.....	7.6	20.0	4.1	.....
	120	16	Earth.....	.....	.....	.....	.....	.....	.....	.....
	136	14	Brown ore...	39.0	.....	.....	15.1	8.0	4.1	.....
	150	3	Blk. Minette	21.0	.....	.....	21.3	5.3	15.7	.....
	162	12	Black ore...	41.1	.....	.....	10.7	4.6	6.0	.....
	165	3	Black ore...	33.0	.....	.....	.....	.....	.....	.....
	168	3	Black ore...	.....	.....	.....	.....	.....	.....	.....
	171	2	Black ore...	37.0	.....	.....	.....	7.0	.....	.....
B	0	13	S. limestone.	.....	.....	.....	.....	.....	.....	.....
	13	5	R. sandy ore	21.0	.....	.....	.....	15.0	.....	.....
	18	25	S. limestone.	.....	.....	.....	.....	.....	.....	.....
	43	4	Red ore.....	24.0	.....	0.53	.....	24.0	.....	.....
	47	17	S. limestone.	.....	.....	.....	.....	.....	.....	.....
	64	5	Red ore.....	27.0	.....	0.59	.....	22.5	.....	.....
	69	6	S. limestone.	.....	.....	.....	.....	.....	.....	.....
	75	7	Red ore.....	28.0	.....	.....	.....	20.0	.....	.....
	82	18	Marl.....	.....	.....	.....	.....	.....	.....	.....
	100	17	Gray ore....	38.0	.....	0.84	.....	12.0	6.0	.....
	117	3	Earth.....	.....	.....	.....	.....	.....	.....	.....
	120	7	Gray ore....	35.0	.....	0.91	.....	12.9	6.3	.....
	127	19	Earth.....	.....	.....	.....	.....	.....	.....	.....
	146	10	Brown ore..	39.3	.....	0.82	.....	6.3	7.7	.....
	156	9	Earth.....	.....	.....	.....	.....	.....	.....	.....
	165	5	Black.....	36.9	.....	0.86	.....	6.8	6.7	.....
	170	4	Earth.....	.....	.....	.....	.....	.....	.....	.....
	174	4	Ore.....	36.4	.....	0.57	.....	6.2	4.5	.....
C	0	9	Limestone...	.....	.....	.....	.....	.....	.....	.....
	9	6	R. sandy ore	26.9	.....	.....	.....	20.0	.....	.....
	15	27	L'stone, marl	.....	.....	.....	.....	.....	.....	.....
	42	4	Yellow ore..	21.3	.....	.....	.....	19.5	.....	.....
	46	8	Blue marl...	.....	.....	.....	.....	.....	.....	.....
	54	2	Gray ore....	35.0	.....	.....	.....	12.0	.....	.....
	56	6	Gray ore....	42.6	.....	.....	.....	6.5	.....	.....
	62	7	Gray ore ...	31.4	.....	.....	.....	15.2	.....	.....
	69	3	Gray ore....	33.3	.....	.....	.....	12.3	.....	.....
	72	2	Gray ore....	29.8	.....	.....	.....	11.7	.....	.....
D	0	81	R.sand, marl	.....	.....	.....	.....	.....	.....	.....
	81	12	Red lime ore	44.5	.....	.....	11.6	6.3	.....	.....
	93	14	Poor M. & marl.....	.....	.....	.....	.....	.....	.....	.....

TABLE XXIV-D—Continued.

Strata and thickness in feet.			Fe	Mn	P	SiO_2	CaO	Al_2O_3	
	107	20 Gray ore....	45.6	.....	.....	12.5	4 .5	.....	.....
	127	12 Blue marl...	.....	.....	.....	.....	.....	.....	.....
	139	16 Brown ore...	39.6	.....	.....	25.5	3.9	.....	.....
E	0	95 Lime ores...	.....	.....	.....	.....	.....	.....	.....
	95	20 Gray ore....	37.6	.....	.....	12.3	10.2	.....	.....
	115	15 Marl	.....	.....	.....	.....	.....	.....	.....
	130	18 Brown ore..	35.5	.....	.....	21.1	6.4	.....	.....
	148	14 Black ore...	42.0	.....	.....	17.0	3.0	.....	.....
									CO_2
F	0	8 Red sand ...	.....	.....	.....	.....	.....	.....	.....
	8	38 Earth	.....	.....	.....	.....	.....	.....	.....
	46	3 Red ore.....	29.4	.....	.....	8.3	20.4	5.9	16.0
	49	19 Earth	.....	.....	.....	.....	.....	.....	.....
	68	2 Yellow.....	34.7	.....	.....	8.7	15.7	5.8	12.9
	70	12 Earth	.....	.....	.....	.....	.....	.....	.....
	82	5 Yellow.....	28.3	.....	.....	17.9	14.4	8.3	11.3
	87	6 Earth	.....	.....	.....	.....	.....	.....	.....
	93	13 Gray	34.1	.....	.....	10.7	14.2	6.6	.....
	106	21 Earth	.....	.....	.....	.....	.....	.....	.....
	127	7 Brown.....	38.8	.....	.....	16.2	4.7	7.8	.....
	134	8 Earth	.....	.....	.....	.....	.....	.....	.....
	142	8 Black.....	32.7	.....	....	21.8	6.9	6.1	.....
									H_2O
Wedding.		Red Calcareous.....	42.9	tr.	0.54	9.9	14.8	4.7	6.8
		Red Silicious	34.5	0.7	0.82	23.6	12.0	5.8	8.6
		Gray.....	38.9	.....	0.92	9.5	12.3	2.3	17.5
		Brown.....	21.5	.....	0.71	16.5	21.0	6.4	25.1
		Green.....	33.4	0.4	0.86	24.4	2.7	10.3	15.0
Stahl und Eisen.			33.2	0.6	0.80	6.8	16.3	5.2	.....
		Rumelange Dudelange..	40.7	0.4	1.00	7.5	7.7	4.7	.....
		Esch.....	39.5	0.4	1.09	13.4	6.4	6.1	.....
			27.6	0.3	0.72	42.0	4.9	4.6	.....
		Differdange la Madelaine	39.2	0.4	0.81	16.1	5.3	6.4	.....
			18.2	0.2	0.58	8.5	33.3	2.3	.....
Kohlmann.									
		Black; thickness 18 feet.....	32 to 45	.....	.....	11 to 22	2 to 7	6	.....
		Brown; 6 to 12 feet.....	36 to 45	.....	.....	5 to 21	4 to 9	.....	.....
		Gray calcareous.....	32 to 41	.....	.....	5 to 15	4 to 14	4 to 6	.....
		Yellow calcareous; 15 feet.....	32 to 36	.....	.....	7 to 9	10 to 15	.....	.....
		Red calcareous; 6 to 12 feet.....	34 to 40	.....	.....	8 to 9	9 to 15	.....	.....
		Red silicious.....	36	.....	.....	26 to 27	2 to 8	.....	.....

Hayange means Hayingen, and Differdange, Differdingen, but can hardly know that Diedenhofen and Thionville are the same.

Lothringen is a part of the Empire, unlike Luxemburg, which is merely connected with it through a tariff treaty. Both districts have the same characteristics, and rely on the enormous bed of iron ore which extends beyond their borders into France and Belgium, and whose known contents will supply iron for many generations. This ore goes by the term "Minette," a contemptuous diminutive once given it by French workmen; this is also the name of one of the French provinces in which it occurs. It is an oolite, consisting of small grains, each one made up of concentric shells of silicious or calcareous matter and hydrous ferric oxide. The beds throughout the greater part of Lothringen carry an excess of lime, but near the

Luxemburg border is a deposit high in silica and carrying 40 per cent. of iron, so that, by mixing, a self-fluxing burden can be obtained, and the usual furnace burden throughout the district runs 31 per cent. in iron and gives 2 per cent. of phosphorus in the pig-iron.

Table XXIV-D shows the composition of different grades of ore. The map shown in Fig. XXIV-B was originally made by Dr. Wedding, but was extended by Kirchhoff. The formation is made up of many different beds, and these vary in thickness, the deposit in the north being 180 feet thick, while in the south it is only 20 feet; but there is no regularity at intermediate points, either in thickness or in the arrangement of interstratified rocks, and there is much faulting, in some cases the throw being 200 feet. As we go southwest into France the beds go down into the ground, get less in thickness and higher in silica. In Luxemburg the mines are owned partly by companies that acquired ownership many years ago, partly by railroads, built to get subsidies in ore lands, partly by farmers and private individuals, while part is controlled by the government. Much of the ore in Luxemburg is sold in the open market, while in Lothringen nearly all the property is in the hands of iron producers, and the great steel works in both Belgium and Westphalia have acquired title to mineral lands. The ore supply in Luxemburg is good for one hundred years, at the present rate of consumption, but in Lothringen for eight hundred years. The mineral domain of this latter province covers one hundred thousand acres, half of which is owned by local steel companies. A good part of the remainder is owned by the companies operating steel works in Westphalia. Kirchhoff mentions the following as having mines in Lothringen and works in the Rhenish district:

Aachener Hütten Act. Verein, Gutehoffnungshütte, Friederich Wilhelmshütte, Phœnix, Union, Hörde, Hoesch, Rheinische and Krupp. In the Saar district we have Gebrüder Stumm, Röchlings, Burbach and Dillengen. Belgium is represented by the Angleur Company and by Cockerills. This list omits the local steel companies of Lothringen, all of which have their own properties.

Considerable ore is sold in the open market in Luxemburg, but little in Lothringen, so that the selling price in the former province will be a better measure of the market. Figures given by Dutreux show that from 1895 to 1899 the average market price varied from

49 to 57 cents per ton, with a general average of 52 cents. The cost to those who possess their own mines must be less than this, but it is hardly likely that it is less than 40 cents, after allowing for a sinking fund. The run of mine will average 31 per cent. in iron, but the ore carried to Westphalia is richer than this. It will run 35 per cent. in iron* and costs 75 cents per ton at the mines. The new freight rate is $1.40 per ton, giving a total of $2.15 per ton of ore delivered in Westphalia, or 6.14 cents per unit.

If the ore is smelted at the mine it is necessary to carry 1¼ tons of coke from the Ruhr to Lothringen at a cost of $1.82 per ton of coke, as the freight on fuel in Germany is one cent per ton per mile. This does not include the cost at the ovens, estimated by Kirchhoff to be $2 for those who own collieries, so that the cost of fuel in Lothringen will be $3.82 per ton of coke or $4.80 per ton of iron. The ore for a ton of pig will cost $1.30, so that the total for ore and fuel sums up $6.10 in Lothringen and $9.10 in Westphalia. I am afraid that this estimate of Kirchhoff assumes a good profit on by-products, but allows nothing for interest and depreciation.

It must be remembered, however, that Lothringen is not a great market. To the southwest is the frontier of France and the French steel works working on the same deposit, while on the northwest are the cheap labor and fuel of Belgium tapping the ore field in Luxemburg. To the south is the mountain barrier of Switzerland, to the east the coal field and iron works of the Saar, and to the north the smoking valleys of the Rhine and the Ruhr. The steel must be carried a long distance and past the doors of active competitors. A great part of the output of Germany is sent over sea and a large part consumed in finishing mills in the northern districts, and, inasmuch as the coal of Westphalia is on the road between the mines and the market, the northern works need not necessarily succumb to the Minette district.

There is a chance for both ends working together, since cheap transportation must include ore going in one direction and coke in the other, and there is opportunity for reductions in charges. The German railroads are owned by the government, and offer a good argument against State control. Like all German official work, they are conducted with honesty, but with an immense amount of

* *Journal I. and S. I.*, Vol. II, 1902, p. 17.

red tape. As a consequence of the honesty and the high freight rates, they pay a profit, but on account of the red tape this money defrays the expenses of the military establishment instead of being used to improve the transportation service. A great deal of money is spent on stations for passenger traffic, but the freight service is not what it ought to be, and the transportation of ore from Lothringen to Westphalia costs 1 cent per ton per mile, while coke and finished material are from 30 to 50 per cent. more. Private ownership of railroads in America has resulted in spending money for improvements, for larger cars and heavier engines, and has cut down the rates far below the German tariff, even though the American roads traverse districts more sparsely settled than the western provinces of Germany.

In addition to the questions of freight which have been discussed, we have the important fact that Westphalia possesses old-fashioned works surrounded by communities of skilled workmen. The task of starting a steel works where such an industry has not existed before is hard enough in America, but in any other part of the world it is still harder, for in our land men are accustomed to move, and readily break away from old associations. A more important matter is the destruction of capital involved in a transfer of the iron industry, for a works in Westphalia cannot be transported bodily to Lothringen. If the attempt were made it is doubtful if twenty per cent. of the money would be utilized, and this being so it becomes cheaper to destroy the old and to build anew. The interest and depreciation on a steel works, including the blast furnaces, is more than the cost of transporting the ore a considerable distance. In a Westphalian works, which is all paid for and has no outstanding bonds, the depreciation account may be neglected and the interest charges looked upon as profit, while in a new works in Lothringen these items become a direct load upon the cost sheet. Thus we find many different ways of working. The old plants in the Ruhr are buying properties in Lothringen and bringing ore to their furnaces and so are the steel works in the valley of the Saar. Other plants are making pig-iron at the mines and sending it to Westphalia and to Aachen, while still other works are being built at the ore bank, the coke being brought from the Ruhr.

The production of the whole Minette district, including Lothringen, Luxemburg and France, was less than three million tons

in 1872, but in 1895 it had risen to eleven million tons. In 1898 it was fifteen million and in 1903 about twenty-two million, of which France contributed five millions, Luxemburg six millions and Lothringen eleven millions.

It has been pointed out by Kirchhoff that the importance of the Minette district is concealed by its situation. The output from the whole deposit in 1903 was twenty-two million tons, which would make eight million tons of pig-iron, but this is divided between three nations, and even the portion which we have considered as German can hardly be called so rightly, since Luxemburg is not an integral part of the Empire. Luxemburg and Lothringen, in 1903, raised three-quarters of all the ore mined in Germany, but the production of pig-iron in the Minette field was only three-quarters as much as in the Ruhr.

In 1899 there were seventeen active blast furnaces in Lothringen and twenty in Luxemburg, which were not connected with steel works in those provinces, but which sold their iron in the open market or shipped it to the Saar or the Ruhr, many of these furnaces being owned and operated by steel works in these two districts. There were twenty-two furnaces in Lothringen and nine in Luxemburg connected with adjacent steel works, so that less than half the furnaces in the district were owned by local steel plants.

The total number of active furnaces in 1899 was sixty-eight, and the production of pig-iron was 2,273,194 tons for the two divisions, representing an average of a little over 90 tons per day for each furnace. Such a calculation of average capacity is not usually of much value, as an old district is likely to have a number of small and antiquated plants, but in the official list published by the Verein Deutscher Eisenhüttenleute there are no very small furnaces mentioned in these two provinces. We may say, therefore, that the average furnace in the Minette district, most of the plants being of modern construction, turns out between ninety and one hundred tons per day, some of them exceeding this considerably. This is done on an ore running only 31 per cent. in iron, but, on the other hand, the mixture is self-fluxing, so that for comparison we must take the ore and limestone together in non-calcareous ores, and, figuring in this way, we will find that Lake Superior ores, when mixed with the usual amount of stone, give about 45 per cent. of iron, so that furnaces working on Minette ores smelt about 50 per cent.

more material than American plants, without taking into account the ash in the fuel. The mixture is not always self-fluxing, for near

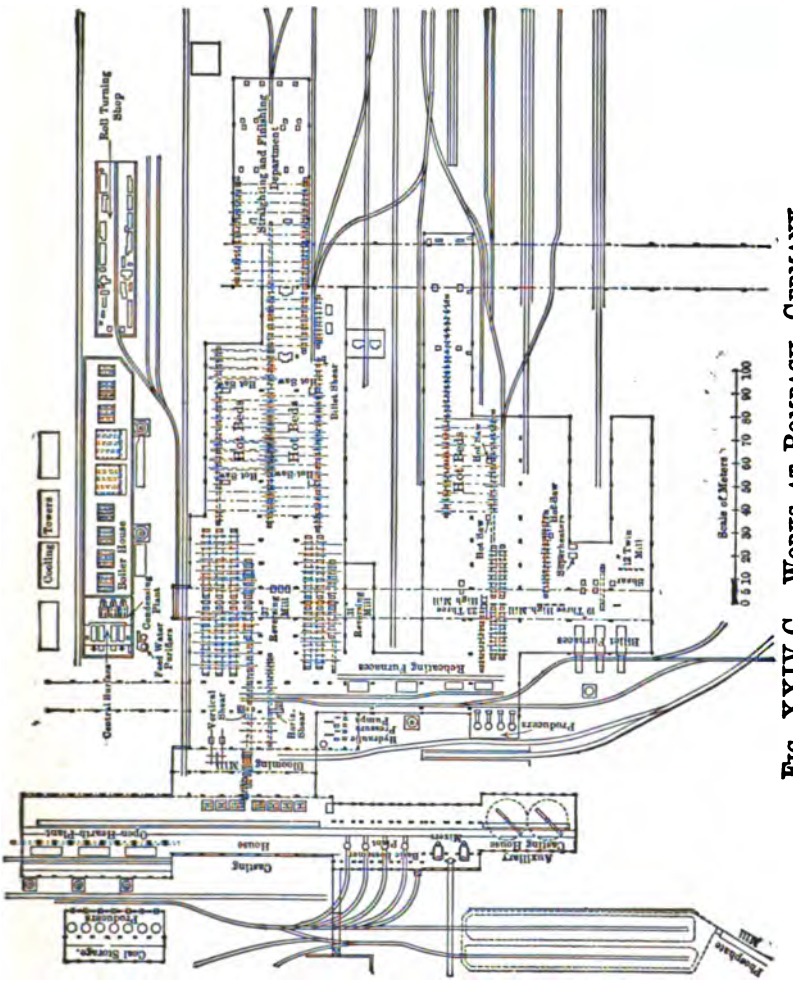


FIG. XXIV-C.—WORKS AT ROMBACH, GERMANY.

the Moselle River the calcareous beds are scarce, and it is necessary to use limestone as a flux.

Most of the blast furnaces use Westphalian coke, the shipments in 1899 from the Ruhr ovens amounting to three million tons, which was 40 per cent. of the total coke output of the northern field. Some

coke is imported from Belgium by plants in Luxemburg, but the German article is far superior. There are three steel works in Lothringen and two in Luxemburg having twenty-six converters from ten to twenty tons capacity. There were only two open-hearth furnaces, one acid and one basic. All the converters are basic.

Three new plants were started in the year 1900, at Rombach, Kneuttingen and Differdingen. In Fig. XXIV-C will be found a drawing of the first of these. It is representative of the best German practice and was started in 1900. The engineer is Bergassessor Oswald, of Coblenz, to whom I am indebted for the drawings. There are seven blast furnaces in the Rombach plant, three of them new, the latter being 90 feet by 23 feet with a 13-foot hearth. It is intended to eventually use gas engines for blowing, and save the steam for the reversing rolling mills. To this end the boiler capacity is large, the pressure being 140 pounds and economizers and superheaters installed. There are two mixers each of 200 tons, feeding 4 basic 17-ton converters. The pig-iron runs from 1.5 to 2.0 per cent. phosphorus and 0.5 per cent. manganese, this latter element being obtained from ores from Spain, the Caucasus and from the Lahn district. The mixture is self-fluxing and runs about

TABLE XXIV-E.

Steel Works with Blast Furnaces in Lothringen and Luxemburg.

District and Works.	Location.	No. of Blast Furnaces and Daily Capacity in Tons.	Bessemer Converters. Number and Capacity in Tons.		Open-Hearth Furnaces Number and Capacity in Tons.	
			Acid.	Basic.	Acid.	Basic.
Lothringen—						
Aumetz Friede..	Kneuttingen	3—130	.....	4—90	1—15	1—15
Rombacher, etc..	Rombach.....	7—140	.....	4—18	.....	.....
DeWendel & Co..	Hayingen.....	7—110	.....	6—12	.....	.....
	Gross-Moyeuvre.	6—110	.....	3—12	.....	.....
Luxemberg—						
Dudelingen, etc..	Dudelingen.....	6—110	.....	6—10	.....	.....
Differdingen.....	Differdingen....	4—120	.....	3—20	.....	.....

31 per cent. in iron. The capacity is now 35,000 tons per month, but this is to be much increased. The Differdingen plant was also constructed with lavish expenditure and an extensive outfit of blowing engines driven by blast-furnace gas was installed. Much

trouble was experienced through dust, although these difficulties have been, in great measure, overcome.

The plant of De Wendel at Hayingen is an example of the system of spare mills, as four complete mills, each with its modern German multiple cylinder engine, stand waiting their turn to run, for there are only men enough to run two mills and only steel enough for that number, in spite of the fact that they are operated in a very slow manner. The building covering these mills includes all the hot beds, finishing machines, storage and loading yards, and is, perhaps, 700 feet by 1000 feet, not including the converting department. The output is about 400 tons per day.

Table XXIV-E gives a list of the steel works and blast furnaces.

List of Blast Furnaces without Steel Works.

	Location.	Owner.	District.	Blast Furnaces.
Owned by Steel Works Elsewhere—				
	Feutsch.....	Aumetz Friede, Lessee.....	Lothringen..	3—120
Lothringen.....	Redingen..... ..	Dillengen.....	Saar.....	2— 90
	Diedenhofen.....	Röchling	Saar.....	2—150
	Ueckingen.....	Gebruder Stumn	Saar....'....	4—120
	Deutsch Oth....	Acieries Angleur	Belgium.....	2— 90
Luxemburg....	Esch.....	Rothe Erde.....	Aachen.....	5—190
	Esch.....	Burbach.....	Saar.....	2—120
Unattached—				
Lothringen.....	.....	.....	.....	7—120
Luxemburg....	.....	.....	.....	13—120

SEC. XXIVc.—*The Ruhr:*

The Ruhr district embraces most of Westphalia and a little of the western shore of the Rhine. It is here we find the coal that gives the best coke on the continent of Europe, though it is not equal to the coke of Durham or of Connellsville. The Ruhr coal district measures fifty miles square, being shown on the map in black with Ruhrort on the western end and Hörde on the east, but coal is found east of Hörde as far as Hamm and extends westward across the Rhine, several mines having recently been opened on the western bank. The works of Krupp at Essen are almost in the center. The deposit covers an area equal to the county of Westmoreland in Pennsylvania or the Durham coal field in northeast England, but Westmoreland raises only ten million tons of coal per year, Durham about forty-six million and Westphalia nearly sixty million. The production of coke in the Ruhr is the same as in

Fayette County, Pennsylvania, which includes the Connellsville beds. The output of Durham is not known accurately, as no statistics are kept in England of this material.

The Ruhr raises half of all the bituminous coal raised in Germany, and makes two-thirds of the coke, and, in addition to supplying western Germany, sends coke to other countries. In 1899 Germany exported 750,000 tons of coke to France and 135,000 tons to Belgium, almost all of this coming from Westphalia. Austria received 600,000 tons, but part was from Silesia. The product of the Westphalian ovens, however, is so much better than the eastern supply that it is carried in large quantities as far as Styria in southern Austria. In 1892 the Ruhr district made 66 per cent. of all the coke made in Germany, but in 1900 its share had risen to 75 per cent. This increase in rank as a coke producer has gone on with remarkable regularity, as shown in Table XXIV-F.

TABLE XXIV-F.

Production of Coke in Germany, by Districts.

Data from Schrödter; private communication. One unit=1000 metric tons.

District	1892	1893	1894	1895	1896	1897	1898	1899	1900
Ruhr	4,560	4,780	5,398	5,562	6,266	6,872	7,374	8,202	9,644
Upper Silesia	1,060	1,060	1,122	1,190	1,269	1,399	1,455	1,516	1,411
Lower Silesia	325	366	416	431	443	424	430	460	536
Saar	587	574	695	713	744	821	887	876	894
Aachen	259	219	207	212	310	251	259	269	267
Oberkirchen	26	27	24	27	27	31	30	33	33
Saxony	82	73	79	70	77	78	72	74	74
Total	6,899	7,099	7,941	8,205	9,186	9,876	10,507	11,430	12,859
Per cent. made in the Ruhr	66	67	68	68	69	70	70	72	75

The exports to Belgium are balanced by coke brought into Luxemburg from that country, the amount so imported being greater than the amount going from Westphalia to Liège. Only a small proportion of the furnaces in Luxemburg import coke, and the amount sent from the Ruhr to Lothringen and Luxemburg in 1899 amounted to 2,783,000 tons, or nearly 40 per cent. of the coke production of Westphalia.

The coal occurs in a great number of beds, the number of workable seams being over two hundred, but none over six feet thick and the average only half that. The thickness of the coal measures

is between seven and eight thousand feet, and they are much folded and faulted. In the southern portion the outcropping beds are nearly worked out, and as mines have been opened more to the north it has been necessary to sink deeper, one shaft going down 2500 feet through strata heavily charged with water. When it is considered that there is more trouble from gas in the deeper mines it will be evident that conditions do not indicate any decrease in the price of coal. The upper beds give a coal containing from 35 to 45 per cent. of volatile matter, the middle region from 15 to 35 per cent. and the lowest seams not over 15 per cent. It is from the so-called "fat" coals of the middle region that most of the coke is made, the ash running about 10 per cent. The sale of coal and coke is controlled by a syndicate which embraces 90 per cent. of the coal output, and the price of fat coal has risen during the last few years from $2 in 1895 to $2.44 in 1900, these figures being at the mine. Kirchhoff quotes the annual reports of many collieries, and the larger collieries, producing one-third of all the coal and coke, show a cost ranging from $1.31 to $1.69 per ton of coal, with an average of $1.55, the smaller collieries running up to $2 and even to $2.50.

The wages of miners have advanced in recent years. In 1878 day laborers received 56 cents and the miners 67 cents, but in 1891 the wages were 71 cents for common labor. A reaction followed and then another rise, and in 1898 common labor commanded 76 cents per day and the miners $1.14. The mining situation in Westphalia is much as it is in the United States, for the development of industry has gone ahead of the increase in native population and one-third of the working force comes from Poland, eastern Prussia and Italy. These alien communities are less common in Europe than in our own land. The selling price at the oven of blast-furnace coke in the Ruhr basin varied from $1.96 per ton in 1887 to $4.95 in 1890. It dropped to $2.75 in 1893, 1894 and 1895 and rose to $3.50 in 1900 and $4.25 in 1901. A great part of this coke is made in by-product ovens, and it is well known that coke-oven builders will operate ovens free of cost for a term of years, taking their pay in by-products. This being so, the price of coke in Westphalia includes a good profit, and the figure given is no measure of the cost to steel works that own mines and ovens, among which are the following:

Hörde, Union, Hoesch, Schalke, Bochumer Verein, Krupp, Gutehoffnungshütte, Phœnix, Rheinische, and Deutsche Kaiser.

In iron ore, Westphalia occupies a very subordinate position. A small amount of blackband is raised, containing 35 per cent. of carbon and 28 per cent. of iron, mainly in the form of carbonate, but the quantity is inconsiderable. Sixty per cent. of the ore comes from the Siegen, the Lahn and Lothringen, and the remainder from over sea. Spain contributes 20 per cent. of the total ore smelted, and Sweden 15 per cent. The supply from the Siegen is spathic ore, which is roasted before using; it contains 35 per cent. of iron and is described in the account of that district. The ores from the Lahn and from Lothringen are also described in the proper place. The Minette ore brought to the Ruhr is richer than the average. The composition runs as follows: Fe, 32 to 38 per cent.; SiO_2, 6 to 8 per cent.; CaO, 10 to 18 per cent. The usual furnace burden in Westphalia carries 35 to 40 per cent. of this ore, 35 to 40 per cent. of Swedish (Grängesberg or Gellivare) and 10 per cent. of spathic ore from Siegerland or brown ore from Nassau, the remainder being cinder, pyrites residue, etc.

Many well-known steel works of this part of the country are not of the type familiar to American metallurgists. They are produced by slow accretions rather than by one comprehensive plan, and it is seldom that any improvement involves the destruction of existing plant. Oftentimes there is complete discordance between the equipment of separate departments of the same plant, and a new and up-to-date blast furnace will be running alongside a legacy of 1840. A massive new blooming mill will be found supplying small finishing mills that hold together only by the force of habit, while the most economical steam engine will be operated in conjunction with one abandoned by James Watts. These conditions obtain sometimes in America, but they are incidental and temporary, existing only during a period of reconstruction, while on the Continent they are typical and almost universal in the old plants of Westphalia.

The cost of pig-iron made from Spanish ores is given by Kirchhoff at $13.75 per ton. The large quantity of ore imported of this kind would lead to the conclusion that the cost of basic pig-iron is nearly as high, but this ore is used almost entirely by two works, Krupp's and Bochum, these being the only large producers of acid

Bessemer steel in Germany. The product is used for special steels, the acid metal being considered preferable.

Kirchhoff gives figures from the reports of several companies to show the profits of the industry. It is impossible to make any statement of profits and losses for these old plants, which have their own sources of raw material and sell everything from coal to machinery, but I have made a rough calculation that in the year 1898-99 the profits of Gutehoffnungshütte represented $6 per ton on a production of 300,000 tons of steel. At Phœnix with an output of 330,000 tons, and at Bochum with 227,000 tons, the profit was $4 per ton. The taxes at Gutehoffnungshütte amounted to 44 cents per ton, and the funds for workmen's pensions, etc., footed up 48 cents per ton, while at Phœnix the taxes were 53 cents and the pensions 30 cents. These taxes and pensions include the mines, coke ovens, etc., and the profits include all subsidiary branches of the plant, but I have calculated the results on the output of steel, as these plants are miscellaneous steel producers and may rightly be compared with many works in America.

In Krupp's works there are fifteen acid-lined Bessemer converters, each of 5 tons capacity, and at Bochum there are 3 of 8 tons, a total of 18 acid vessels with an average of 5⅓ tons capacity. The output of acid Bessemer steel in 1899, in the Ruhr district, was 118,000 tons. It is quite certain that these converters were not worked to their full capacity, but if we assume that all the acid Bessemer steel was made at Krupp's the production will be only 660 tons per converter per month. In America we do not have many converters of this size, but twenty years ago, when the steel industry was in its infancy, it was considered that 120,000 tons per year was the proper output for two converters of this size, supplied with one ladle crane and pit. In other words, the product for each acid converter in Westphalia to-day is one-tenth what it was in America twenty years ago.

No attempt has been made, either in Westphalia or in Lothringen, to specialize the rolling mills, and there is little thought of steady operation for large production, the controlling idea being that it is impossible to change rolls quickly, and that spare mills must lie idle, ready to start on a different section. The weak point of this plan is that it is difficult to arrange the hot bed and finishing part of the mills so as to serve two different trains of rolls. In one of the new

plants working on structural shapes, at the time of my visit in 1899, the chaotic condition of the hot bed and cold bed and loading department was something which cannot be described. This branch of rolling-mill work is the weakest feature of German practice, while the operation of heavy blooming and reversing mills is the strongest.

The output of acid Bessemer steel is small, being only one-tenth of the basic tonnage, and the acid open hearth contributes only one-tenth as much as the basic furnaces. Half the steel is made in the large steel plants, meaning by this that they operate both blast furnaces and a Bessemer plant, while the rest was made in small plants and steel-casting works, the latter having 21 furnaces averaging 9 tons each.

I am informed by Mr. Schrödter that "there are several works which turn out 32,000 to 35,000 tons in a month, from either two or three basic converters of 18 to 20 tons capacity, using one vessel at a time." I have received personal communications from four German works giving me the output of their converters. The first four plants are in the Ruhr district, while Rothe Erde is at Aachen.

Works.	Size of converter.	Tons per month per converter.
Phœnix	12½ tons	7,000
Hoesch	11 tons	8,000
Horde	18 tons	8,000
Rheinische	15 tons	6,500
Rothe Erde	15 tons	7,500

A basic lining in a converter is considered to do well if it lasts 220 heats, while the bottoms average 45 to 50 heats. It is the practice to run one vessel at a time, and this will make three heats per hour, since the time of blowing is about twelve minutes. Every sixteen hours the bottom must be changed, while delays occur from repairs to tuyeres. When such a delay does occur, another vessel is brought into use until the repairs are completed. Sometimes the vessels are used alternately when the iron is blowing hot, and sometimes heats are made out of turn to keep the lining hot on an idle vessel, as a basic lining suffers from becoming too cold. At the end of three days the first vessel will be worn out and relining takes fifteen hours and firing about six hours more. While this is going on the second and third vessels must be working and there are many times when a fourth unit is needed, the newest plants being designed on this basis. The output will not increase in proportion to

the number of the converters, but each unit renders possible a more uniform output per hour.

This regularity is of more importance in Germany than in America on account of the use of unfired soaking pits. The first round of ingots on Monday morning is kept in the pits only twenty minutes, and rolled into blooms, as it is not hot enough to finish into rails or billets. The next round stays forty minutes, and the next sixty minutes, after which the mill goes on throughout the week finishing billets, rails, beams, or other shapes at one operation. During a roll change in the finishing mill, the blooming mill may make blooms or large billets, and it is the general practice to have at least two finishing mills supplied from the same blooming mill, and these run alternately so that one is always ready. One

TABLE XXIV-G.

Westphalian Steel Plants and Blast Furnaces.

Note:—Figures on blast furnaces are estimated daily capacity; all the steel plants having blast furnaces at the steel works, use direct metal.

Name of works.	Location.	Blast Furnaces.	Bessemer Converters.		Open-Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Bessemer steel works with furnaces at works—						
Hörde Bergw	Hörde	7—160	.....	4—18	1—18	7—18 2—7
Union	Dortmund	9—160	.....	4—18	.....	4—25 1—8
Hoesch	Dortmund	3—200	.....	3—11	.....	4—18
Bochum	Bochum	4—140	3—8	3—3½	.....	7—25
Gutehoffnungshütte	Oberhausen	3—140	.....	4—12	.....	6—15 1—4
Phœnix	Ruhrort	3—100 3—150	.....	3—12	1—12	4—20 1—12
Rheinische	Ruhrort	3—270	.....	4—15	.....	4—10
Deutcher Kaiser	Bruckhausen	4—300	.....	4—18	1—15	7—15
Bessemer steel works with blast furnaces elsewhere—						
Krupp	Essen	.....	15—6	.....	9—10	18—21
Furnaces at	Duisburg	.....	.....	.....	.....	.....
	Hochfeld	3—100	.....	.....	.....	.....
	Rheinhausen	3—200	.....	.....	.....	.....
	Neuwied	2—80	.....	.....	.....	.....
	Müllhofen	4—75	.....	.....	.....	.....
Furnaces at	Eschweiler	.....	.....	.....	.....	4—14
	Berge Borbeck	2—150	.....	.....	.....	.....
	Kupferdreh	1—125	.....	.....	.....	.....
Bessemer Plants without blast furnaces—						
Haspe	Haspe	.....	.....	3—6	.....	.....
Stahl Industrie	Bochum	.....	2—8	.....	.....	2—12
Steel works without blast furnaces	.....	.....	.....	.....	6—12	64—15
Blast furnaces without steel works	.....	20—110	.....	.....	.....	.....

of these is generally equipped to roll small billets. In this way the converting department and the soaking pits are kept running steadily and loss from oxidation in the heating furnaces is unknown. To the average observer a German plant, turning out from 1000 to 1500 tons per day, seems to be operating at a very low cost, in spite of there being a few more men than would be found in America.

There were 147 basic open-hearth furnaces in the Ruhr district in 1899 with an average rating of about 17 tons, and these make about 1,800,000 tons of open-hearth steel per year; the output of Bessemer steel is nearly 2,500,000 tons. The total steel made is about 4,300,000 tons, while the output of pig-iron is only 4,000,000 tons, the difference being made up by metal brought from the Minette region. The district is the great producer of wrought-iron, there being 500 puddle furnaces at work, or half the number in the Empire. Table XXIV-G gives the principal producers of steel and iron, but it will be understood that the estimated capacity of blast furnaces represents a maximum hoped for, rather than a regular production. Thus the seven furnaces at Hörde are rated at 160 tons when the figures for 1898 show an average product of 90 tons, and the same reports give 90 tons for the furnaces belonging to the Union Works, 130 tons for the Hoesch, and 110 tons for Gutehoffnungshütte.

SEC. XXIVd.—*Oberschlesien, Upper Silesia:*

In the southeastern end of Germany, surrounded on the north, east and south by Russia and Austria, lies a district fifty miles square, which produces half as much coal as the Ruhr Valley, one-fourth as much coke, and which stands second among German districts in the production of steel. Isolated by the political frontier lines and by the mountainous character of the country, it forms a factor not only in the industrial world, but in the political situation, for tariff measures and expenditures for internal improvements by railway or canal must be arranged to give this district its share in the benefits, in order that it may not pay taxes to assist a competitor.

Coal is found in both Upper and Lower Silesia, but the iron industry exists only in the east. The character of the population is quite different from that of western Germany, for eastern Silesia formed part of the old province of Poland, as might be inferred

from the names of the towns. It is more provincial; wages are lower; the standard of living is not as high, and the proximity of Russian Poland, Austria and Hungary gives rise to a great deal of floating foreign labor. The primitive character of the population is indicated by the traveling bazaars, temporarily established in the market places of the towns. The wares are the crudest hand-made articles, ranging from shoes to augers, and could not be sold in an up-to-date community except to a museum. Gangs of Russian women travel around in search of work as Croatian or Austrian workmen go from one place to another in America, and these women, as well as others from Austria and from the home villages, work in the steel works, on the railroads, or any place where there is work to be done, beginning this drudgery at the age of sixteen. Their wages are 25 cents per day, while men earn from 50 to 62 cents.

The principal advantage possessed by Silesia is its coal supply. In 1899 it raised 28,000,000 tons of coal, which was over half as much as Westphalia produced, and made 1,777,000 tons of coke, one-quarter of the amount turned out in the Ruhr. The coal is rich in volatile matter, running from 30 to 35 per cent., but gives a poor coke. Efforts have been made to improve the quality by stamping the coal, this being done both wet and dry at different works, and although it is questioned whether any good is done by this compression, the burden of evidence seems to be in its favor. The Silesian coal field reaches into Moravia and Poland and will be further referred to in the discussion of Austria and Russia. Formerly considerable ore was mined in Silesia, but the supply is decreasing, for in 1894 there were 600,000 tons raised, while in 1903 there were only 390,000 tons. This ore is poor stuff of the following composition:

	Per cent.
Iron	25
Manganese	2 to 3
Silica	30 to 40
Zinc	0.8
Water	30

In the dry state this means Fe, 36 per cent.; silica, 43 to 57 per cent.; Zn, 1.1 per cent. These figures were given me on the spot by the manager of one of the blast-furnace plants, and they agree with results recorded by Bremme, Stahl and Eisen, Vol. XVI, p. 755.

The ore is very fine and there is an immense amount of flue dust mixed with troublesome sublimate containing zinc. About 35 per cent. of lime is needed as a flux. The local furnaces are gradually ceasing to use this ore, but I found the works at Donnersmarckhütte carrying it to the extent of 50 per cent. of the burden. Foreign ore is now used in the blast furnaces, the amount brought to the district in 1899 being 330,000 tons from Hungary and 275,000 tons from Sweden, the quantity of foreign ore smelted being 40 per cent. more than the domestic product. The Hungarian ore is a carbonate and is roasted before using. It comes from Kotterbach, south of the Tatra Mountains, some of the mines being owned by the works at Friedenshütte. It is singular that Friedenshütte should have been one of the first works to install gas engines driven by furnace gas, when the local conditions of dust would make the trial almost a crucial test, and when coal for firing boilers can be had for $1 per ton.

TABLE XXIV-H.

Steel Works and Blast Furnaces in Upper Silesia.

	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Steel works with blast furnaces—						
Friedenshütte	Friedenshütte	4—110	.....	4—12	.....	2—17
Königshütte	Königshütte	7—80	1—8	2— 8	.....	4—12 1—10
Bethlen Falva	Schwientochlowitz	8—75	.....	.....	.....	2—?5
Borsigwerk	Borsigwerk	8—75	.....	.....	.....	4—15
Hubertushütte	Oberlagiewnik	8—70	.....	.....	.....	4—20 2—20
Steel works without blast furnaces—						
Huldschinsky'che	Gleiwitz	.....	1—8	1—8	.....	2—15 1—20
Baildonhütte	Kattowitz	.....	.....	.....	.....	3—15 1—20
Bismarckhütte	Schwientochlowitz	.....	.....	.....	.....	1—20 3—15
Blast furnaces without steel works—						
Julienhütte	Bobreck	7—60	.....	.....	.....	.....
Donnersmarckhütte	Zabrze	8—75	.....	.....	.....	.....
Three others, one each						

The steel works of this district are of the usual German type. They are troubled, like a larger proportion of Continental and English plants, for lack of water. In America most works have been

placed in some advantageous position, but in Europe they "just grew," and seldom are near a sufficient water supply, as a good-sized river, according to foreign standards, carries about enough water to cool two or three blast furnaces, and condensers are a luxury. This disadvantage is overcome by the use of central condensing plants, which are much more common than with us, and by cooling towers. The cooling is not enough to give a good vacuum, and the clouds of vapor are a nuisance in summer and winter. Many plants use the condensed water to return to the boilers and have elaborate settling and skimming tanks to separate the oil, but much remains to be done to give clean water.

The statistics for 1903 show 33 blast furnaces in operation, making 753,000 tons of iron, an average of 62 tons per day per furnace. There were two acid Bessemer converters of 8 tons capacity, and 7 basic vessels of 10 tons. There were 30 basic open-hearth furnaces, averaging 16 tons, in the larger steel works, and a few others in steel-casting plants. There are no acid open-hearth furnaces in the district. Silesia is a large producer of wrought-iron, there being 287 puddle furnaces in operation, or 30 per cent. of the total for Germany,

In Table XXIV-H is a list of the steel works and blast furnaces.

SEC. XXIVe.—*The Saar:*

The Saar district is 40 miles square, with an underlying bed of coal. It includes Saarbrucken and western Bavaria. The coal is not of the best and gives a poor coke, which would hardly be used in America, but that it can be used is proven by the steel works at Volklingen and Burbach. There are four plants in the valley, and three of them make most of their pig-iron at the steel works, but these three, and the fourth also, operate furnaces in Lothringen or Luxemburg and bring the pig to the Saar. The coal varies, and at one works which I visited it ran from 22 to 30 per cent. of ash, and in another from 18 to 20 per cent. In both places it was crushed and washed and the ash reduced to 10 per cent., giving a coke with 12 to 14 per cent. The coal is rammed with an electric rammer before charging, compressing the mass so that the coke is more dense and the amount used for smelting is decreased 10 per cent. The yield of coke is 70 per cent. of the weight of dry coal. Scarcely any of this coke is carried outside the valley of the Saar, but the local blast furnaces use it exclusively.

The ore is brought from the Minette district, and the mixture is self-fluxing, containing about 31 per cent. of iron, and the pig carries 2 per cent. of phosphorus, the practice being the same as in

TABLE XXIV-I.

Steel Works and Blast Furnaces in the Saar District, with the Number of Furnaces and Rated Capacity.

	Location.	Blast Furnaces.	Bessemer Converters.		Open Hearth Furnaces.	
			Acid.	Basic.	Acid.	Basic.
Steel works with blast furnaces—						
Burbach	Burbach	5—120	.....	4—11	.....	8—15
also at Esch, Luxemburg	.....	2—120	.....	.....	.....	.....
Röchling'sche	Volklingen	5—120	.....	4—15	.....	.....
also at Didenhofen Lothringen	.....	2—180	.....	.....	.....	.....
Gebruder Stumm	Neunkirchen	6— 60	.....	4—12	.....	1—12
also at Ueckingen Lothringen	.....	4— 80	.....	.....	.....	.....
Steel works with furnaces elsewhere—						
Dillingen	Dillingen	.....	.....	3—15	1—15	1—20 2—25
Furnaces at Redingen Lothringen	.....	2— 60	.....	.....	.....	3—15
Steel works without furnaces—						
Weber	Hostenbach	.....	.....	.....	.....	3—15
Eisenwerks Kramer	St. Ingbert	.....	.....	3—12	.....	.....
Blast furnaces without steel works—						
Halbergehütte	Brebach	4— 80	.....	.....	.....	.....

Lothringen, save that the coke is inferior to the Westphalian fuel. There are 20 blast furnaces in the Saar, and in 1903 they smelted 736,000 tons of pig-iron, or a little over 80 tons per day per furnace, reckoning them as all in operation. There were no acid converters and only three acid open-hearth furnaces. There were four basic Bessemer works with 18 converters of an average capacity of 13 tons, and 16 basic open-hearth furnaces of an average capacity of 16 tons.

Table XXIV-I gives a list of the steel works and blast furnaces.

SEC. XXIVf.—*Aachen (Aix la Chapelle):*

The immediate neighborhood of Aachen possesses a bituminous coal field which in 1899 raised 1,764,000 tons of coal. This gives a fair coke and the output of the ovens in the above year was 337,000 tons. There is also a deposit of lignite from which nearly

4,000,000 tons were mined. The output of this kind of coal is increasing for use in making steam and similar purposes, a large proportion being made into briquettes. The ore production is small, being only 16,580 tons in 1899. There are some scattered blast furnaces which made 153,000 tons of iron during the year. The district is important as a steel maker on account of the works at Rothe Erde, on the outskirts of Aachen. This plant makes no pig-iron at its works, but operates five furnaces at Esch in Luxemburg, all the pig-iron going to Rothe Erde for remelting. There are three basic converters of 15 tons each, which made 287,000 tons in the year 1902, or 8000 tons per month for each vessel. There are also three open-hearth furnaces of 25 tons capacity. The Rothe Erde works are progressive and have an extensive system of cranes, commanding their storage and shipping yards, quite unusual in foreign works and not at all common in American plants. A conspicuous feature is a high crane covering traveling cranes of ordinary height and span and transferring material or even the smaller and lower cranes themselves.

SEC. XXIVg.—*Ilsede and Peine:*

In the southeast corner of the province of Hannover, between the towns of Hannover and Brunswick, is a deposit of brown iron ore mined by open cut, the bed varying from 6 to 41 feet in thickness.

TABLE XXIV-J.

Composition of Ilsede Ores.

(Wedding: Eisenhütten Kunde; 1897, Zweite; p. 33.)

	Aluminous.	Calcareous.	Washed Ore.	Phosphoric.
Fe_2O_3	58.26	44.16	62.73	16.41
MnO	7.81	4.72	5.26	1.00
SiO_2	10.70	3.90	4.87	3.09
Al_2O_3	4.76	1.00	1.02	1.16
CaO	5.09	21.61	8.90	31.50
MgO	0.44	....	....	0.91
P_2O_5	2.46	2.15	4.08	25.96
H_2O+CO_2	10.98	22.46	13.14	19.97
Total	100.00	100.00	100.00	100.00
Metallic Iron, wet.	40.8	30.9	31.3	11.5

The composition is given in Table XXIV-J, the material called "washed ore" being obtained by washing the clay from the fine ore

produced in mining, thus obtaining clean grains of ore. The ore is used raw and is self-fluxing, giving a pig-iron containing about 3 per cent. of phosphorus, which is the best for basic Bessemer practice of any iron in Germany. It is smelted at Ilsede in three blast furnaces of 200 tons each, and the fuel ratio is about 1 to 1. The records of manufacture for 223,000 tons of pig show that 2.925 tons of ore were used per ton of pig-iron, while the coke was 1.008 tons. The coke is brought from the Ruhr, a distance of over 150 miles, with a freight rate of $1.58 per ton, but it has been estimated by Schrödter that the cost of pig-iron was only about $6.75 per ton, in an era of low prices a few years ago. In 1899, owing to high cost of fuel and supplies, the pig-iron cost $9.10 and in 1900 it was $10.10. A local supply of lignite helps keep the wolf from the door. In 1902 the output of ingots was 239,000 tons, about 20,000 tons per month. The pig-iron is converted into steel at Peine, three miles away, where there are four basic converters of 15 tons capacity.

SEC. XXIVh.—*Kingdom of Saxony:*

The Kingdom of Saxony, which must not be confounded with the province of the same name, is on the border of Austria, touching Silesia on the east, while Bavaria lies on the west. It contains a good supply of fuel, and in 1899 raised 4,500,000 tons of bituminous coal and 1,300,000 tons of lignite. Some of this coal will make coke, and 72,000 tons were so used in the year mentioned. There are some deposits of ore, but the amount is unimportant. No pig-iron is smelted, but pig-iron is brought in from outside and the district around Chemnitz shows quite a development of the steel industry. A small amount of puddled iron is also made. There are four steel works. One has two acid converters of six tons capacity, which in 1902 made 11,000 tons of steel, and another has three basic converters of 15 tons, which made 40,000 tons. There is one acid open-hearth furnace of eight tons and eleven basic furnaces of 13 tons. There are also some small steel-casting plants.

SEC. XXIVi.—*The Siegen:*

Siegerland includes the southern portion of Westphalia and the eastern arm of the Rhine province. It has no coal, but raises a large amount of ore, most of this being a carbonate occurring in mammoth fissure veins of great extent. The ore is mined by shafts averaging about 700 feet in depth, and is roasted before smelting, the loss in weight being 30 per cent. About two-thirds of the output

is smelted in the district, the rest going to the Ruhr or the Lower Rhine. In 1899 there were 2,120,000 tons of ore raised, which was one-eighth of the total for Germany. The calcined ore, according to Brugmann,* runs from 47 to 48 per cent. in iron, 8 to 10 per cent. in manganese and 9 to 12 per cent. in residue. The distance to the Ruhr is 90 miles and the freight 70 cents per ton. The cost delivered is $4.40, the low phosphorus and high manganese making the ore desirable.

There are 32 blast furnaces in the district, four of them operated by steel works. These have a daily capacity ranging from 70 to 110 tons, but the others are smaller, the average rated capacity being only 60 tons. The pig-iron production in 1899 was 657,000 tons, which is 30 tons per day for each furnace, but many of the old furnaces are making spiegeleisen, a considerable proportion of the output running 20 per cent. in manganese. Much pig is used for puddling, there being over one hundred furnaces in the district, or 10 per cent. of the total for Germany. There are four steel works in the district, concerning one of which the German records give no information beyond a question mark. The other three make only basic open-hearth steel, having 12 furnaces of an average capacity of 13 tons. The output of steel in 1902 was 154,000 tons.

SEC. XXIVj.—*Osnabruck:*

The district of Osnabruck lies at the junction of western Hannover and northern Westphalia; being only 50 miles from the Ruhr it might be included in that district, but it possesses its own coal and ore beds and thus stands by itself. In 1899 it raised 550,000 tons of bituminous coal and 128,000 tons of ore. The ore comes from the Hüggel and though low in phosphorus is very friable. Brügmann gives its content as from 15 to 25 per cent. of iron, with much moisture. The iron industry is centered in the Georgs-Marien-Bergwerks, at Osnabruck. There are four blast furnaces, and in 1899 the production of pig-iron was 115,000 tons, or about 80 tons per day for each. There are two acid converters of seven tons, and three basic open-hearth furnaces of twenty tons each.

SEC. XXIVk.—*Bavaria:*

The iron industry of Bavaria consists of the Eisen. Ges. Maximilianshütte, at Rosenberg in Oberpfalz. It has two blast furnaces,

Journal I. & S. I., Vol. II, 1902.

three basic converters of five tons capacity and two basic open-hearth furnaces of fifteen tons.

SEC. XXIVl.—*The Lahn:*

The district known as the Lahn begins at Coblenz and stretches northeastwardly through Hessen Nassau, south of the Westerwold range. It is known for its red and brown hematites, large quantities being sent to Westphalia. In 1899 the Lahn raised 750,000 tons of ore, this being one-third of what was mined in the Siegen. The average run of red hematite is 50 per cent. in iron. The ore is carried 130 miles to Westphalia, with a freight rate of 97 cents; the delivered price is $3.80 or 7.6 cents per unit. This neighborhood also supplies ore, carrying 22 to 38 per cent. of iron, 7 to 8 per cent. of manganese, and 18 to 25 per cent. of residues. This is laid down in Westphalia for $3.50 per ton.

SEC. XXIVm.—*Pommerania:*

A new tidewater plant of three blast furnaces of the Eisenwerk Kraft, near Stettin on the Baltic Sea, has been built to smelt imported ore, coal being brought from England and coked in by-product ovens. The iron is for foundry use, and by its situation this plant has easy access to Berlin, one of the greatest markets in the world on account of the business done in miscellaneous castings.

CHAPTER XXV.

FRANCE.

I am indebted to my friend, Mr. August Dutreux, of the Cie. des Forges de Châtillon, Commentry et Neuves-Maisons, for a careful reading of the manuscript of this article.

SECTION XXVa.—*General View:*

The iron industry in France is spread over the whole country, as will be seen in Fig. XXV-A; many seats of industry date back many years, but the control of the situation rests in the ore beds of the Minette district on the borders of Luxemburg and Lothringen. This deposit has been fully described in the chapter on Germany, and it was stated that the ore extended into the province of Meurthe et Moselle. The French iron business was discussed in *Journal I. & S. I.*, Vol. II, by H. Pinget, secretary of the Comité des Forges de France; through the courtesy of M. Pinget I am in possession of the statistics for 1900, and also the number of converters and open-hearth furnaces in each province and their output. I have grouped these provinces in the usual way, the results being shown in Table XXV-A. The map in Fig. XXV-A gives the output for 1899.

Early in 1900 I was able to enlist the services of the American Chamber of Commerce in Paris in the collection of statistics concerning the different provinces of France. The results are shown in Fig. XXV-B.

SEC. XXVb.—*The East:*

The eastern division embraces the great ore deposit in the province of Meurthe et Moselle and the neighboring districts of Haute Marne, Ardenne and Meuse. The map of the Minette district, given in connection with Lothringen, will indicate the position of mines and steel works. All basic Bessemer plants in the Minette district are in Meurthe et Moselle, but the other three provinces make the greater part of the open-hearth product, and their output is increas-

ing. The fuel must be brought quite a distance, and as the Belgian coal fields are as near as those of northern France, and since the coke from the French deposit is not of the best, and since it has

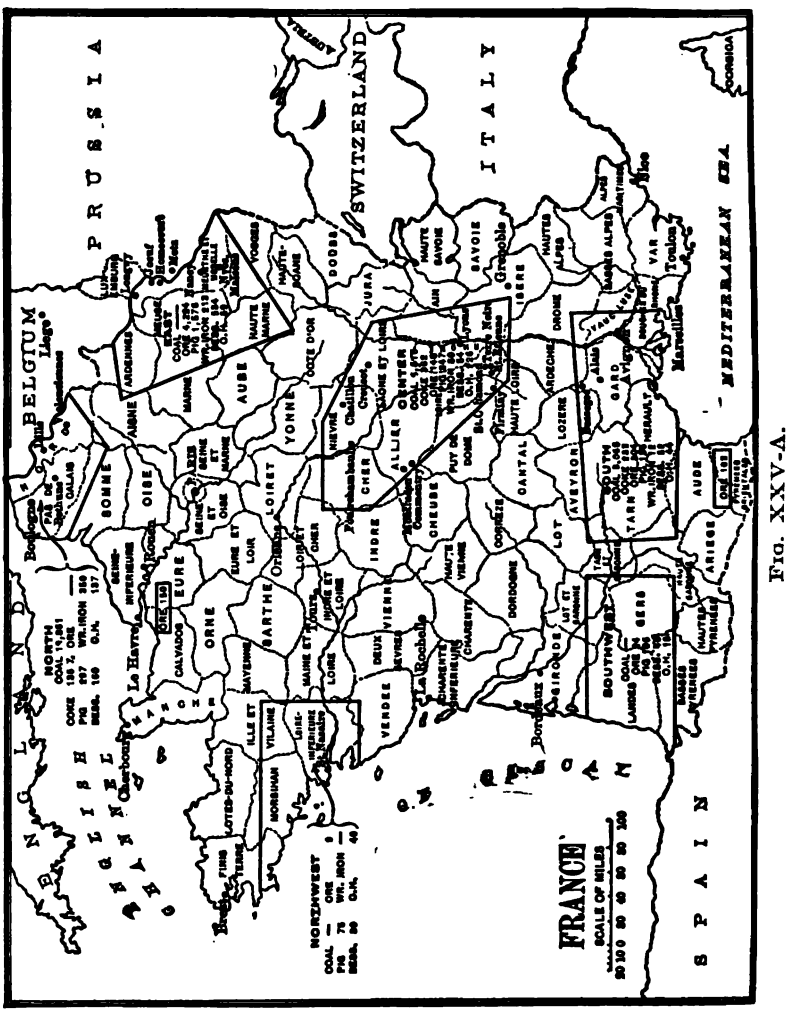


FIG. XXV-A.

been impossible to get a sufficient supply, there is a large amount of coke brought from Germany and Belgium in spite of the tariff. The Pompey Company has ovens at Seraing, Belgium, but as a

rule the companies do not control their fuel supply, although very lately the furnaces around Longwy have united to form a coke com-

TABLE XXV-A.

Production of Fuel, Ore, Iron and Steel in France; metric tons.

Data marked thus * are for 1898.

Production in 1899.	Coal.	Coke.	Ore.	No. of Blast Furnaces in Operation in 1904.	Pig Iron.	Wrought Iron.
East	.....	.....	4,224,000	66	1,576,000	213,000
North	19,861,000	1,357,000*	.....	12	297,000	350,000
Centre	6,516,000	362,000*	148,000	14	247,000*	80,000*
South	3,065,000	233,000	204,000	10	136,000*	12,000
Southwest	.....	.....	24,000*	7	106,000*	.....
Northwest	.....	.....	9,000	2	75,000*	.....
Others	3,421,000	.....	377,000	1	.....	61,000
Total	32,863 000	1,952,000	4,986,000	112	2,578,000	884,000
Imports	12,370,000	.....	1,951,000	.....	.....	.....
Exports	1,028,000	.....	.....	.....	.....	.....

Production in 1900.	No. of Steel Works.		Bessemer.		Open Hearth.		Total Steel.	Rails in 1901.
	Total.	With Bessemer Converters.	No. of Converters.	Product.	No. of Furnaces.	Product.		
East	9	6	19	554,890	8	71,104	625,994	119,873
North	4	3	9	232,329	13	138,548	370,877	72,289
Centre	10	1	2	52,128	42	261,788	313,916	.....
South	3	1	2	33,326	10	59,769	93,095	48,798
Southwest	1	1	2	45,579	2	15,434	61,013	33,000
Northwest	2	1	3	32,909	5	54,602	87,511	17,859
Others	5	.....	.....	.....	10	66,542	66,542	.....
Total	34	13	37	951,161	91	609,787	1,620,948	291,814
Total for 1903	.....	.....	.....	1,172,984	.....	681,636	1,854,620	.....

pany. A plant of 500 ovens has been built, but a sufficient supply of coal is not available, as the coal companies prefer to make coke in their own ovens. For this reason some of the large steel companies are acquiring coal mines in the Pas-de-Calais district.

In 1898 this district produced 60 per cent. of all the basic Bes-

semer steel made in France, and at that time there were only four works in operation, the Longwy, Micheville, Joeuf and Pompey. Other works have started which will overshadow these completely, from which some idea may be formed of the complete supremacy of

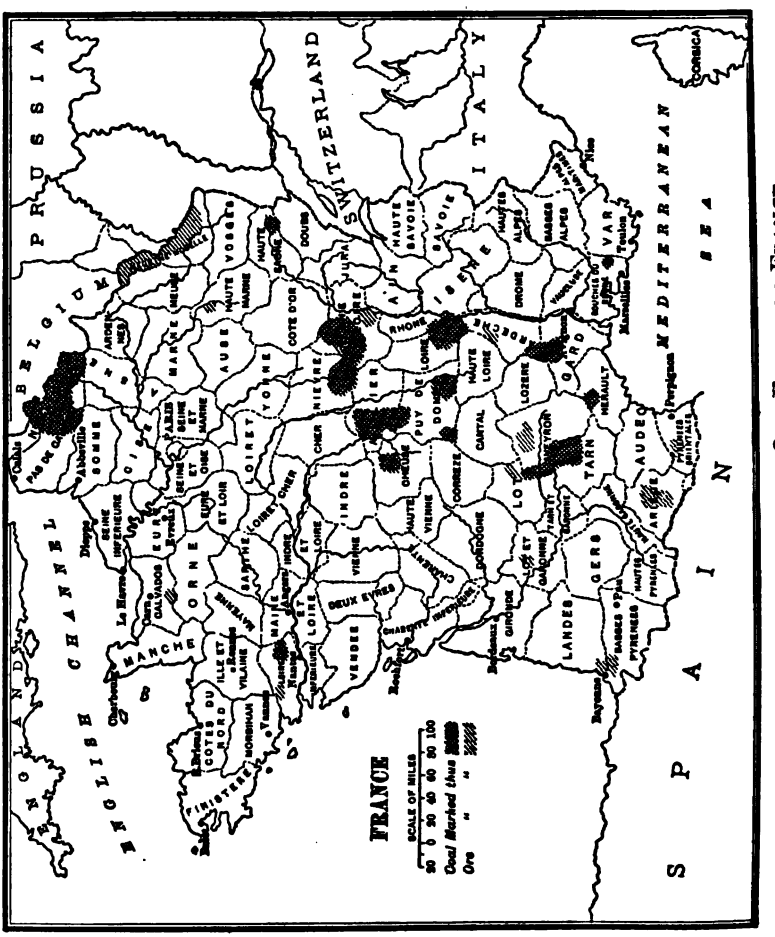


FIG. XXV-B.—COAL AND ORE FIELDS OF FRANCE.

this district. It is customary to consider Meurthe et Moselle as made up of three districts, Longwy, Joeuf and Nancy; but they are exactly alike in metallurgical conditions.

In the Longwy division there are three steel plants of moderate capacity, as follows:

(1) The Longwy Company, which in 1901 produced 169,670 tons of pig-iron and 149,556 tons of ingots.

(2) The Micheville Company, which in 1901 made 155,730 tons of pig-iron and 125,854 tons of ingots.

(3) The Société des Forges de Montataire, with a new works at Frouard, with three eight-ton converters.

In the Joeuf district are two steel works:

(1) Compagnie des Forges et Aciéres de la Marine et d'Homecourt. This is a new company formed by the union of the Soc. Vezin Aulnaye with the Forges et Aciéres de la Marine. There are now two blast furnaces, but one more is to be built immediately. There are three 18-ton converters with an estimated capacity of 1200 tons per day. In 1901 the works made 102,023 tons of pig-iron and 110,262 tons of ingots.

(2) The old plant of De Wendel, in which Schneider & Co., of Creusot, are interested, has a rated capacity of 500 tons per day, but is of an antiquated type. Owing to the relations existing between France and Germany no railroad connection is allowed with the works, since it brings its ore by rail from German territory, and all its products are hauled by cart to the existing French railroad.

The third district of Nancy has two steel plants:

(1) The Pompey Company at Pompey.

(2) A new works being built at Neuves-Maisons by the Compagnie des Forges de Châtillon, Commentry et Neuves-Maisons. This company is one of the oldest and largest in France and has operated works for many years in the central district at Montluçon, Commentry and elsewhere, and it is very significant when such a new departure is taken and a large works projected in a district entirely disconnected with all preceding operations. The new plant is to include five blast furnaces and four 18-ton converters.

In addition to the blast furnaces connected with steel works above mentioned, there are others making iron for the general market, and on January 1, 1900, there were 65 furnaces completed, with 54 in blast, the total capacity being estimated at 5000 tons per day. It is unnecessary to discuss the metallurgical situation in this locality as it has been covered by the description of Lothringen. Table XXV-B gives a list of the works in this district.

TABLE XXV-B.

Steel Works in the East of France.

Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Meurthe-et-Moselle	Société anonyme des Aciéries de Longwy (B)	Mont-Saint-Martin
	Société anonyme des Aciéries de Micheville (B)	Micheville
	MM. de Wendel et Cie, Maitres de Forges (B)	Joeuf
	Société anonyme de Vezin-Aulnoye (B)	Homecourt
	Société anonyme des Hauts-Fourneaux, Forges et Aciéries de Pompey (B)	Pompey
	Société anonyme des Forges et Fonderies de Montataire (B)	Frouard
Meuse	Société anonyme des Forges et Aciéries de Commercy	Commercy
Haute-Marne	Compagnie des Forges de Champagne et du Canal de Saint-Dizier a Wassy	Marnaval-Saint-Dizier
Ardennes	MM. Boutmy et Cie, Maitres de Forges	Messempré-Carignan
	MM. Lefort et Cie, Maitres de Forges	Mohon

SEC. XXVc.—*The North:*

The great coal field of France lies in the provinces of Nord and Pas-de-Calais. It is an extension of the Belgian deposit and extends from the border to beyond Bethune; the city of Valenciennes may be regarded as a center. The developments in Pas-de-Calais are rather recent. An extension of the Nord coal fields has been exploited at depths ranging from 2300 to 4000 feet, and the French steel works have taken advantage of the new discoveries to acquire independent coal supplies. The coke is not of the best quality, but the Belgian is little better, and the demand has been ahead of the supply owing to the development of the iron industry in Meurthe et Moselle, so that although there are now 2000 coke ovens in operation and many more in process of erection, the price of fuel in France has been almost prohibitive. In the year 1900 coal retailed in Paris at $15 per ton and coke for foundry use as high as $10. These prices, which were exceptionally high even for France, encouraged imports in spite of a duty of 25 cents per ton, and coal from the United States entered Mediterranean ports, while England sent 6,000,000 tons of fuel, including coal and coke, and Germany supplied considerable coke. Belgian and English fuel is im-

ported into the coal region itself, for in 1899 the foreign coal used in the provinces of Nord and Pas-de-Calais was one-sixth of the total consumption. In the province of Calvados in the northwest, a short distance from the French coal fields, nearly all the fuel was brought from England. It is the intention of French coke makers to increase the number of ovens so as to render imports unnecessary, but it is doubtful if this increase can affect the northwestern and southwestern works, which are close to the sea and which will find English coke cheaper, as well as better. The cost of mining in the Nord and Pas-de-Calais field is enhanced by the depth of the shafts and by the dislocations and contortions of the strata, and the coal must compete on the east with the product of Belgium and Germany and on the west with English fuel.

A certain amount of iron has been made in this district, but the great drawback has been the absence of any ore deposit, the supply having been drawn from Meurthe et Moselle, or from Spain and Sweden. For years there has been a small amount of hematite mined in the province of Calvados. I am informed that there has now been discovered the mother lode of spathic ore in large quantities and of good quality. The freight on this will be low owing to empty cars returning northward to the coal districts, and it is thus possible to establish an iron center in the District of the North. To what extent this may develop remains to be determined. Table XXV-C gives a list of the steel works in the district.

TABLE XXV-C.

Steel Works in the North of France.

Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Nord	Société anonyme des Hauts-Fourneaux, Forges et Aciéries de Denain et d'Anzin (B)	Denain
	Société anonyme des Forges et Aciéries du Nord et de l'Est (B)	Trith-Saint-Leger
	Société anonyme des Usines de la Providence	Hautmont
Pas-de-Calais	Société anonyme des Aciéries de France (B)	Isbergues

SEC. XXVd.—*The Center:*

The central district embraces the provinces of Loire, Saone et Loire, Allier, Rhone, Cher, Isere and Nievre, and the works at Creusot, Montluçon, Commentry, St. Chamond, Firminy and St.

Etienne. Notwithstanding this array of names familiar to metallurgists, the output of this part of France may be briefly passed over. It is of small amount and the existing works have become specialized, making high-grade products for a limited market, as, for instance, armor plate, guns and tool steels. The fuel supply is not good, the blast-furnace coke of St. Etienne in the Loire basin containing an average of 14 per cent. of ash. The supply from

TABLE XXV-D.

Steel Works in the Center of France.

Note: Those marked (B) have Bessemer Converters.

Province.	Companies.	Location.
Allier	Compagnie des Forges de Châtillon. Commentry et Neuves-Maisons	Montlucon and Commentry
Isere	MM. Ch. Pinat et Cie, Maitres de Forges	Allevard
Loire	Compagnie des Forges et Aciéries de la Marine et des Chemins de fer	Saint-Chamond et Assailly
	Compagnie des Fonderies, Forges et Aciéries de Saint-Etienne	Saint-Etienne
	MM. Claudinon et Cie, Maitres de Forges	Le Chambon-Feugerolles
	Société anonyme des Aciéries et Forges de Firminy	Firminy
	MM. Jacob Holtzer et Cie, Maitres des Forges	Unieux
Nievre	Société anonyme de Commentry-Fourchambault et Decazeville	Imphy
Saone-et-Loire	MM. Schneider et Cie, Maitres de Forges. (B)	Le Creusot
	MM. Campionnet et Cie	Gueugnon

Allier, which goes to Commentry, Montluçon, etc., is no better, while much of the fuel for the Creusot works comes from the Burgundy basin in Saone et Loire, and for the making of coke must be mixed with one-third of the coal from St. Etienne. Ore is wanting, over one-third the supply being brought from Spain, and there seems to be no future development possible as far as international metallurgy is concerned. The whole district in 1899 made only 4000 tons of rails, which was but a little more than one per cent. of the total output of steel. The Creusot works turn out a very fair product, but much of their pig-iron is brought from more favored districts. This plant makes almost all the few rails made in this part of the country, and quite a little material for ships, and claims attention on account of its miscellaneous business in machinery, ordnance and structural work; but there is little danger that the establishments of central France will make many conquests in international

trade in the lines of heavy machinery or structures until their present methods of hand labor are revolutionized. In the southern part of this division Algerian ore is used, as well as some from the Pyrenees. In 1888 there were 24 blast furnaces reported in blast, but ten years later, in 1898, only 16 were in operation. Table XXV-D gives a list of the steel works in this district.

SEC. XXVe.—*The South:*

The southern district covers the provinces of Gard, Aveyron, Ardeche, Bouches du Rhone and Ariege, and includes the coal field of Alais in Gard, which gives a coke that is used in the blast furnaces of Besseges and Tamari. There is also a deposit in Aveyron, which, though poorer than the Alais coal, will run over 18 per cent. in volatile matter and will give a marketable coke in Coppée ovens. In the southeast there are deposits of lignite, the province of Bouches du Rhone raising 490,000 tons in 1899, and neighboring districts contributing 117,000 tons. Some of this is sent to

TABLE XXV-E.

Steel Works in the South of France.

Note: Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Ariege.....	Société Metallurgique de l'Ariege.....	Pamiers
Aveyron.....	Société anonyme de Commentry-Fourchambault et Decazeville.....	Decazeville
Gard.....	Compagnie des Mines, Fonderies et Forges d'Alais. (B)	Besseges and Alais

Switzerland and Italy. The quality of this fuel is not good and the supply is scant, so that one-quarter of all the coal consumed in this part of the country is imported from England. The iron industry has received an impetus from recent developments in the Pyrenees; these mountains have long supplied ore in moderate quantities, but it is likely that the output will be increased. Some ore is brought from Algeria. In 1888 there were nine blast furnaces in operation, while in 1898 there were eleven in blast, some of these in the region near the Pyrenees being small and using charcoal for fuel. Table XXV-E gives a list of the steel works in the district.

SEC. XXVf.—*The Northwest (Loire Inferieure) and the Southwest (Landes):*

Both these divisions import Spanish ores from the north of Spain and smelt with English coke. The works in Loire Inferieure bring some pig-iron from other provinces of France. The production of neither district is of importance, although both contribute quite largely to the rail output. At the works at Trignac, near St. Nazaire, there are three blast furnaces, three 10-ton converters and four open-hearth furnaces, the production of Bessemer steel being about 2500 tons per month. The works in the two districts are given in Table XXV-F.

TABLE XXV-F.

Steel Works in the Northwest and Southwest of France.

Note: Those marked (B) have Bessemer converters.

Province.	Companies.	Location.
Loire-Inférieure	Société anonyme des Acieries, Hauts-Fourneaux, Forges et Aciéries de Trignac. (B)	Trignac
	Société anonyme des Forges et Acieries de Basse-Indre	Basse-Indre
Landes	Compagnie des Forges et Aciéries de la Marine et des Chemins de fer. (B)	Le Boucau

CHAPTER XXVI.

RUSSIA.

I am indebted to Mr. A. Monell, formerly of the Carnegie Steel Company, for a careful reading of the manuscript in conjunction with a naval attache of the Russian Government. The manuscript has also been read by Mr. Julian Kennedy. Much information has been taken at first hand from the Russian *Journal of Financial Statistics* and *The Mining Industries* of Russia, and some from Consular Report No. 555 of the British Foreign office. A paper by Bauerman, *Journal I. & S. I.*, Vol. I, 1898, and articles in *Stahl und Eisen*, by Neumark and Houvy, furnished much in the way of detail. A description by Head* of the South Russian industry has also been drawn upon. In statistics concerning Russia, the weights are given in poods and the values in roubles. One pood is about 36.14 pounds, and hence 62 poods are one gross ton. A rouble is 51.5 cents, and this is one hundred kopecks or copecks.

SECTION XXVIa.—*General View:*

Within ten years Russia has trebled her production of pig-iron and increased her output of steel fourfold. No other nation can show such a record. All the force of an autocratic government has been applied to the building up of home industries; ore is admitted free, a bounty is paid on all pig-iron exported, and the freight rates are very low, while pig-iron pays a duty of $14.00 per ton and steel plates $29. The Government owns two-thirds of the railways, pays $40 per ton for rails, and it buys 40 per cent. of all the pig-iron that is not converted into steel. In 1899 the price of foundry pig in South Russia was $25.50 per ton, but in the panic of 1901 it fell for a time to $14.50. Four-fifths of the population in Russia are rude mediæval peasants, using few iron implements. The Government is, therefore, almost the only purchaser of iron products.

The policy has been to encourage manufacture, especially in South Russia, and the large dividends attracted foreign capital. The New Russia Company, the oldest and largest steel works, has declared dividends since 1889 of from 15 to 125 per cent. In 1899 the aggregate capital of foreign companies in Russia was over $70,000,000, more than half being in mining interests. The Bel-

*Journal Society of Arts, London, Dec., 1902

gians especially have taken an active part in the iron industry, and out of a total of 55 blast furnaces in South Russia, 21 are operated by Belgian capital. Many extensive plants have been built without inquiry into local conditions, relying on the Government to buy whatever was made at such a price that dividends could be declared. The Bourses of the Continent swallowed anything with a Russian name, but the inevitable crisis came in 1899 and 1900, the Government refusing to pay exorbitant prices, and a process of natural selection is now in progress. The situation of many concerns is indicated by the official report of a French company, which pathetically but almost humorously states that the plant they have built in the lonely forests of the Ural is suffering from "the absence of mines and railways near the works." Naturally, this great crisis has had its effect on the imports of iron and steel, as shown in Table XXVI-A.

TABLE XXVI-A.

Imports of Iron, Steel and Fuel into Russia; tons.

	1897	1898	1899	1900
Pig iron	100,000	113,000	139,000	50,000
Iron	300,000	320,000	270,000	97,000
Steel	90,000	74,000	48,000	20,000
Iron and steel goods	270,000	280,000	300,000	220,000
Coal	2,150,000	2,500,000	4,000,000	4,000,000
Coke	400,000	450,000	550,000	540,000

The importation of iron and steel fell off owing to the necessity of finding a market for the home production. The imports of coal and coke did not decrease, because they are brought to the plants in Northern Russia and Poland which depend entirely on outside sources of supply.

Everywhere in Russia the iron manufacturer has two troubles: If he is near coal, the ore is uncertain or being rapidly exhausted; if near good ore, there is no fuel. In either event the labor is inefficient, for the men come from the agricultural class and seldom break off connection with their native village, many working in factories only during the winter and going back to the farms in the spring. The Government watches over them with paternal care. No man may work continuously for twelve hours, and at night the hours must not exceed ten. On days preceding holidays the day work must not be over ten hours, and work must cease at noon the

day before Christmas. There are fourteen holidays, in addition to Sundays, obligatory on members of the Russo-Greek Church, and there are many regulations about individual written contracts with each laborer, to violate which is a serious offense for either work-

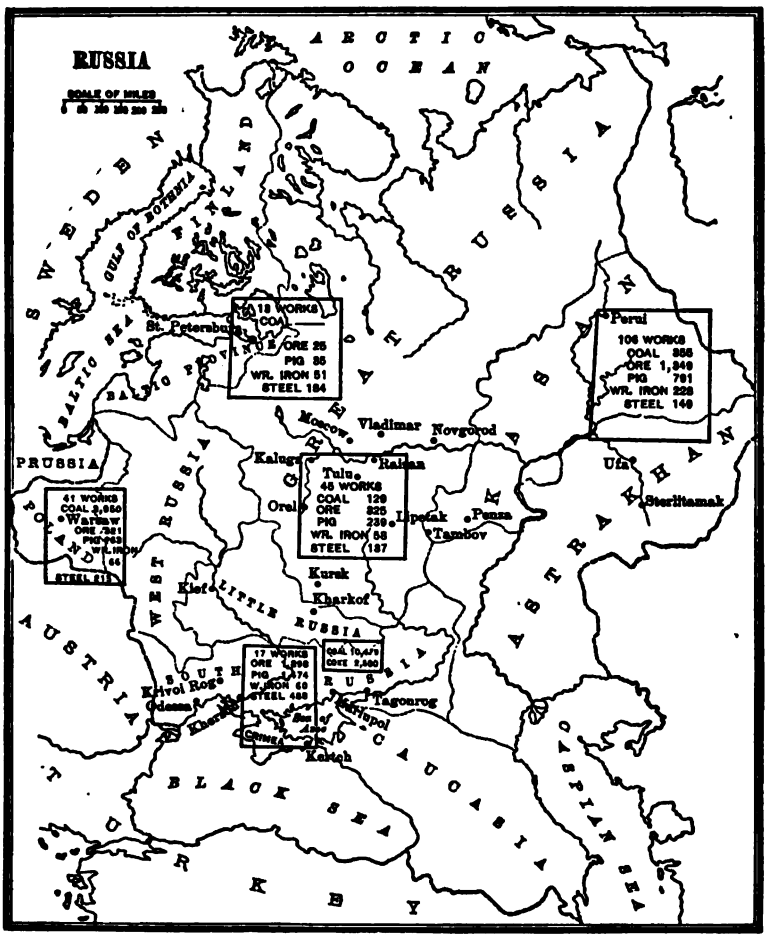


FIG. XXVI-A.

man or employer. For joining a strike a man may serve a year in prison, as this involves a violation of a written agreement. These rules, although enforced with autocratic completeness, are tempered by regulations that allow for accidents and for extraordinary repairs.

The Government insists on complete arrangements regarding the health and welfare of the workmen in their home life. The New Russia Company, in Southern Russia, employs 14,500 workmen. Only 150 of these are women, a showing which compares more than favorably with conditions across the Austrian border. The company supports a hospital with 106 beds and a dispensary with six doctors, five surgeons' assistants, two midwives, one apothecary and two assistants, the cost of this department amounting to $36,000 per year. It supports a system of schools costing $75,000 per year, and tea houses, baths, etc., etc. That all this is good cannot be questioned, but that it is a regulation of the State bespeaks a paternal government, and a people who need a paternal government, and this is a people who are in a certain stage of evolution and who must develop for more than one generation before the common peasant becomes the industrial equal of the artisan of America.

As might be expected in a country so great, there are several centers of production, and owing to the undeveloped condition of transportation the distances intervening between these centers acts as a commercial protection. This is true in every country to a greater or less extent, but Russia presents extreme examples. The

TABLE XXVI-B.

Approximate Annual Output of Coal, Ore, Iron and Steel in Russia; tons.

District.	Coal.	Ore.	Blast Furnaces.			Pig Iron.	Steel.	Wrought Iron.
			Cold Blast.	Hot Blast.	Total.			
South	11,750,000	3,120,000	3	37	40	1,350,000	980,000	60,000
Urals	350,000	1,610,000	33	102	135	640,000	290,000	350,000
Poland	4,000,000	490,000	2	33	35	300,000	280,000	70,000
Moscow	100,000	650,000	9	45	54	90,000	190,000	50,000
North	.....	30,000	4	5	9	20,000	180,000	90,000
Siberia and Finland	.....	90,000	3	17	20	30,000	20,000	20,000
Total	16,200,000	5,990,000	54	239	293	2,430,000	1,940,000	540,000

Moscow district, in the center of Russia, is 600 miles from the works in Poland, or from those in Ekaterinoslav, while Poland and South Russia are separated by an equal distance. The Ural district

is still more isolated, being nearly 900 miles from Moscow, 1200 miles from the Sea of Azov and more than that from Poland. Fig. XXVI-A shows the distribution of the iron industry and Table XXVI-B gives more definite statistics. The output of steel in 1899 was 1,939,000 tons, but it has decreased since then on account of business conditions. One-third of the output in 1899 was made in the Bessemer converter and two-thirds in the open-hearth furnace. The output of rails was 530,000 tons, about one-quarter being made by the New Russia Company.

SEC. XXVIb.—*The South:*

The predominant factors in Russian development are the South Russian coal fields in the basin of the Don and the ore beds of Krivoi Rog. The coal deposits cover an area of about 8000 square miles and contain fourteen thousand million tons of fuel. There are nearly three hundred mines opened, but three-quarters of the product comes from fifteen openings. The seams are of moderate thickness, not exceeding seven feet and as a rule from three to four feet. One seam which is worked is only sixteen inches. Head gives $1.92 as the cost of a ton of coal and $3.35 for a ton of coke, both figures being the cost at the mines. The district in 1888 produced 2,205,000 tons, 6,686,000 in 1897 and 12,000,000 in 1903, being three-quarters of all the coal that was raised in Russia. The coal varies from lignite to anthracite, the same seam being quite different in places a few miles apart. The anthracite beds are more extensive than those furnishing soft coal, but the furnaces at Salin are the only ones using hard coal for smelting. The bituminous varieties are high in sulphur, ranging from 1 to 4 per cent. The coke is of poor physical structure and most of the coal needs to be washed, several plants for this purpose having recently been put in operation. The best beds give a coke containing 8 per cent. ash and 1.1 per cent. sulphur, but other coals give up to 25 per cent. ash and 4 per cent. sulphur. In 1900 there were made 2,500,000 tons of coke, but not more than one-third the coal used for this purpose could be called true coking coal. The volatile matter at some plants is 18 to 21 per cent., while in other places the proportion is higher. In 1900 there were 4000 ovens, two-thirds of which were of the Coppée type, no by-product plants being in use.

The ore in the basin of the Don is of little importance, the nearest deposits being in Krivoi Rog in Kherson, on the border of

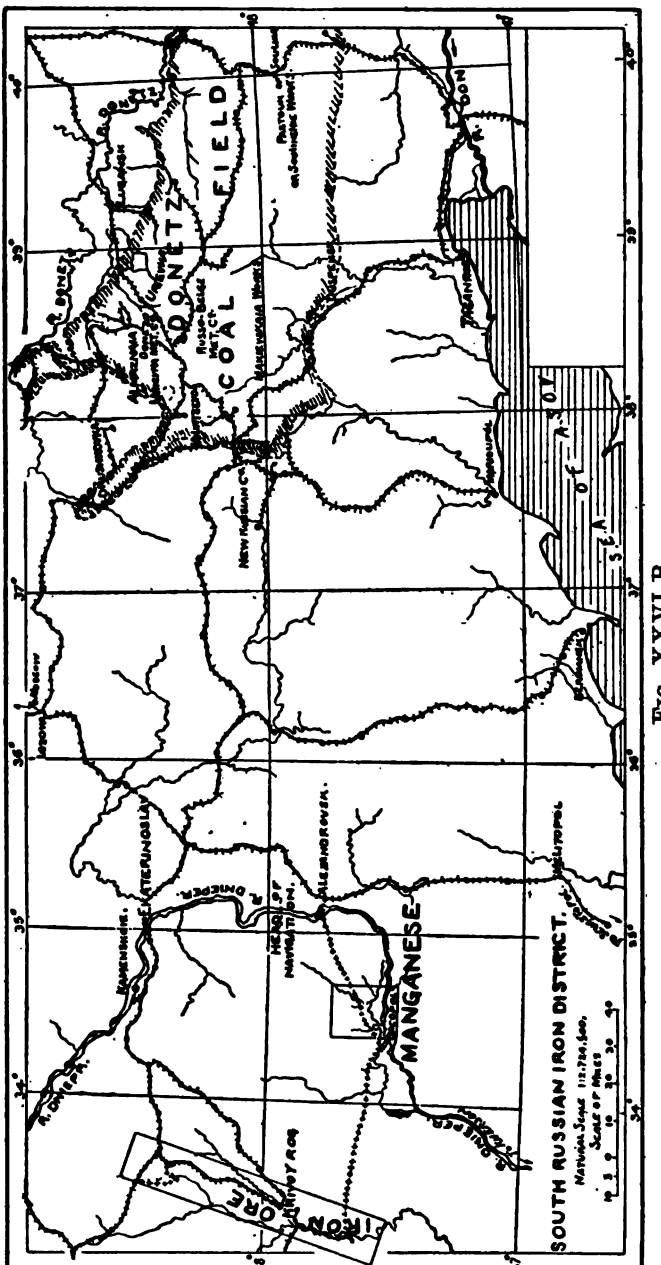

DONETZ
COAL
FIELD
IRON
MANGANESE
SOUTH RUSSIAN IRON DISTRICT.
Natural Scale 1:1,728,000.
Scale of Miles
0 10 20 30 40
S. E. A. of A. of T.
DNIEPER R.
DON R.
KRIVOY ROG
KAMENSKOE
KREMENTCHUG
ALEXANDROVSK
MARIUPOL
TAGANROG
BAKU
BATOUM
BLACK SEA
CASPIAN SEA

FIG. XXVI-B.

Ekaterinoslav. The deposit varies greatly in composition and character, the richest ore being pulverulent and giving trouble in the blast furnace on account of this fine condition. Most of the beds are near the surface and are mined open-cut. Head gives the following as representative:

Dried at 212° F.	Fe.	P.	SiO_2	Combined water.
Southern beds	58.4	.095	8 2	6.45
Northern beds	67.8	.082	4.7	3.20

The amount in sight is limited and most of the good deposits are owned by companies that smelt their own output and sell no ore. The cost of a ton of Krivoi Rog ore, including 16 cents royalty, is given by Head as $1.28. The steel works are scattered along the railway from the ore mines to the coal field, a distance of 260 miles, but the freight rate for the long haul is about 0.64 cents per ton-mile, and the average freight on ore for the works in the coal basin will be about $1.90, giving a total cost of $3.18 per ton of ore, delivered at the coal district.

Large deposits of ore have also been opened at Kertsch, about 300 miles to the south across the Sea of Azov, the bed being near the surface and worked with steam shovels. The layer is 30 feet thick, but the upper and lower portions are poor, and only the middle stratum, comprising two-thirds of the whole, is used. Neumark states that the ore runs from 40 to 46 per cent. in iron, and that the cost of pig-iron made from it is from $11 to $12.50 per ton. On the other hand, Head says that the "Kertsch deposits are not important," and in the discussion of his paper it was stated that this ore contained only from 20 to 22 per cent. of iron.

In 1899 the production of ore in South Russia was as follows:

	Tons.
Krivoi Rog	2,650,000
Local Donetz	180,000
Kertsch	190,000
Total	3,020,000

South Russia in 1887 produced only 161,000 tons of iron ore, but in 1897 the output had risen to 1,898,000 tons, and in 1899 to

3,120,000 tons or over half the output of the Empire. In 1900 it was estimated that the Kertsch peninsula would raise 600,000 tons. The tonnage of wrought-iron and steel in 1899 was twelve times what it was ten years before. In 1888 this district made only 13 per cent. of the pig-iron and 18 per cent. of the steel made in Russia; in 1899 it made over 50 per cent. of both pig-iron and steel.

In addition to these products South Russia turns out 100,000 tons per year of manganese ore, but this is overshadowed by the Caucasus region in the southeast, which furnished one-half of the entire supply of the world. The output of manganese ore from the Caucasus in 1900 was 662,000 tons averaging 53 per cent. of manganese. During that year Russia exported 440,000 tons. In 1900 there were 17 iron works in South Russia, the most important being given in Table XXVI-C, the new works in Kertsch not being included. Most of these works own collieries in the Donetz field and ore mines in the Krivoi Rog district. Table XXVI-C shows that over half the works are in the coal region.

TABLE XXVI-C.

Principal Iron and Steel Works in South Russia in 1900, and Annual Production of Iron and Steel.

	Pig iron; tons.	Finished iron and steel; tons.	Number of men employed.
Near the Donetz Coal Field:			
New Russia Company	270,000	153,000	8,319*
Petrovski, Russo-Belgian Met. Co	148,000	107,000	2,689
Donetz-Yurieff Met. Co.	110,000	32,000	3,240
Donetz Ironworks and Steel Co.	95,000	76,000	2,371
Olkovaia Furnaces and Works Co.	80,000	.....	458
Sulinski	40,000	.....	3,091
Near the Krivoi Rog Ore Field:			
South Russia Dnieper Met. Co.	210,000	170,000	6,626
Alexandrovski, Briansk. S. Russia Co.	145,000	90,000	7,174
On the Sea of Azov:			
Taganrog Met. Co.	80,000	65,000	3,122
Nikupol Mariupol Min. and Met. Co.	76,000	23,000	1,619
"Russian Providence;" Mariupol	70,000	40,000	1,841

SEC. XXVIc.—*The Urals:*

The Ural district presents problems of peculiar interest. The ores have long been known and the iron from the beds of Mount

* It has been previously stated on the authority of the Russian *Journal of Financial Statistics*, that the number of workmen in 1899 in all the works of the New Russia Co. was 14,500. It is stated in a British Consular Report that the number is 8,319. It is probable that the latter figure omits some of the mines or associated industries.

Tagil has been famous all over the world. The deposits are scattered over quite a distance north and south, both on the eastern and western slopes of the range, and lie between 54° and 60° north latitude and 56° and 62° east longitude, an area about 240 by 420 miles. Some of the beds are brown ore, occurring in strata 130 feet thick and containing 60 per cent. of iron after roasting, while other deposits are of magnetite and are among the most important in the world.

The chief center of the eastern Urals is near Nisjne Tagual, where the hill known as Wissokaia Gora offers a deposit about a mile square, in which the best ore runs from 60 to 65 per cent. in iron. The famous iron mountain of Blagodat is thirty miles north of Nisjne Tagual [redacted] three miles from the Kouchwa station on the Ural Railway. This mountain is seamed with ore running from 52 to 58 per cent. in iron. The more northern deposits in the Ural district are difficult of access, but the southern are on the line of the railway from Perm to Ekaterinburg.

In 1888 this district produced over one-half of all the pig-iron made in Russia. Since then the proportion has decreased, owing to the growth of South Russia, but the actual tonnage of pig-iron has doubled and the output of steel increased ninefold. This development has gone on in spite of the fact that good fuel is scarce. There are large deposits of coal, but the quality is bad, the ash running from 17 to 23 per cent., and it gives a poor coke. A little anthracite is found on the western side of the mountains, but it has not been used to any extent. The almost universal fuel is charcoal, and this is not always of the best. In the southern part pine wood is used and the blast furnaces are built as much as 59 feet high, this being the maximum allowable, but northward the charcoal becomes poorer and the possible height of the furnaces less, so that in the Central Urals they are only 50 feet and in the northern part only 42 feet, the average production for one furnace per day being twenty tons.

It may seem impracticable to carry on metallurgical operations on a vast scale when charcoal is the only available fuel, but certain things must be taken into account. First: The great iron district of South Russia is 1200 miles away—rather far for Russian railways—and when it comes to water transportation the advantage is all the other way, for the Ural iron works would be shipping *down stream*.

This is an important matter in Russia, where there is an immense commerce in the transportation of products down river on rafts and barges which are broken up for lumber at the end of the journey, there being no need of a return cargo.

Second: The Russian Government prohibits the destructive deforesting of lands, so that the same area may be reckoned as affording a sure supply of charcoal in a given number of years.

Third: After allowing for the growth of population, the Urals have 40,000,000 acres of perpetual forest land, equal to a space 250 miles square, and this will produce charcoal sufficient to make 4,700,000 tons of pig-iron per year. This charcoal can be made for $4.25 per ton.

Fourth: The ore is abundant and some of it of the best quality.

These facts are not disputed and it becomes a question why there is not a more rapid development in the region. This subject was made the occasion for an investigation by the Government. It was shown that onerous restrictions and routine imposed by the Government itself were responsible for much of the trouble, in great contrast to the encouragement given to industries in South Russia. Quite as serious a matter was the system of land tenure, for a great part of the land has not yet been allotted to the serfs set free a generation ago, and as no man knows what land he will have or how much he will get, it can hardly be expected that he will take much interest in any part of it, or spend money on improvements. Another factor is the law providing that landed proprietors must furnish steady work to people living on the estate, and under these circumstances it can hardly be expected that labor-saving machinery will be introduced.

A peculiar feature is the status of what are styled "Possession Works." These are owned by the Government and leased to individuals or companies. They embrace 6,000,000 acres of forest land, equal to an area 100 miles square, and the blast furnaces produce 200,000 tons per year, or one-third the production of the Urals. The terms of lease prohibit the proprietor from making improvements or changes without special authority from the State. There are numberless petty prohibitions, as, for instance, the sub-letting of leaseholds, etc., that render an efficient management entirely out of the question. Coupled to these conditions is the natural opposition of mediæval feudal proprietors to changing the existing order.

Some day the spirit of enterprise which is now transforming Russia may take hold of this remote corner of the Empire, and when the great plains of Siberia and Eastern Russia are more thickly peopled we may have the curious condition of an immense iron and steel producing district with charcoal as the only fuel.

It may also be possible that some of the best ores may be transported 1200 miles to the Donetz coal basin, or that the coal may be taken to the ore. The prohibitive distances intervening between outside countries and the center of the Continent make many things possible when the time comes that the plains of Asia are covered with cities, or when they will be laid out with railway systems as the Great Desert of our own West has been reconstructed in a generation.

One solution to the transportation problem in the Urals is being given by a company which is building a plant of six 15-ton open-hearth furnaces at Tsaritain on the Volga. The pig-iron will be made in charcoal furnaces in the Urals and be brought 900 miles on barges by river, and it must all be brought on the summer freshet, as the upper tributaries are only navigable at that time. The fuel is naphtha, which will be brought 700 miles from Batoum by way of the Caspian Sea and the Volga.

One of the principal works in the Urals is the Nijni Tagual, owned by Demidoff, Prince San-Donato. This is near the ore deposits of Blagodat and Vissiokaia and has eleven blast furnaces, twelve open-hearth furnaces and a Bessemer plant. The output of this plant during 1899 was 72,886 tons of pig-iron and 52,070 tons of wrought-iron and steel. This record of the largest and best-known works in the district will give an idea of the general condition. The largest works in the Southern Urals is near the ore mine of Komarowo, but its output is only 2000 tons of pig-iron per month. This ore deposit is a brown hematite, but a little distance to the eastward is an immense deposit of magnetite at Magnitnaja or the "Iron Mountain."

SEC. XXVId.—*Poland:*

With the exception of Ekerinoslav, Poland is the only part of Russia where extensive deposits of coal are found. In 1888 the Dombrova field, in the Bendzin district, province of Petrokov, in Poland, produced 2,376,000 tons of coal, being slightly more than Southern Russia, but in 1903 Poland had increased only to 4,750,-

000, while South Russia raised 12,000,000 tons. The coal of the Dombrovski basin is an extension of the Silesian deposit and gives a poorer coke than is made in German and Austrian territory. The blast furnaces therefore bring almost all their supply from Austrian Silesia and Moravia. This condition has caused a very slow development of the coal industry, the increase in output in the three years from 1897 to 1900 being only 6 per cent. In this latter year Poland produced 26 per cent. of all the coal raised, the South contributing 69 per cent. and all other portions of the Empire only 5 per cent.

There are some deposits of iron ore in Poland, and nearly one hundred mines where brown hematite and spherosiderite are found, but the ore is lean and variable, holding 20 to 50 per cent. of iron and the amount produced is unimportant. In 1899 only 488,000 tons were raised, half of which came from the province of Radom. The composition was 30 per cent. of iron in the raw stone and 35 per cent. when roasted. In recent years the ores of the Krivoi Rog have been brought 700 miles to replace the local supply. There are 40 iron plants in the district, but they are as a rule very small. Almost all the iron is made in four works, of which the principal is the Huta Bankowa, operated by French capital, possessing three blast furnaces making together about 250 tons of iron per day, and eleven open-hearth furnaces. There is quite a forge and tube plant at Warsaw, with open-hearth furnaces running on imported pig-iron, though blast furnaces are now building. The Briansk Company, which has a works in South Russia at Ekaterinoslav, also has a plant in Poland at Grodno.

In 1888 Poland produced 51,000 tons of steel and in 1899 it made 282,000 tons, and yet owing to the advance in South Russia the percentage of total production made in this province was less at the later period.

SEC. XXVIe.—*The Center:*

The district of Central Russia is one of the oldest in the Empire and includes an area two hundred miles square, with Moscow at its northwest corner. There is a little coal found here, but it is the worst in Russia, being high in ash and sulphur and of poor structure. Formerly there were large forests, but two-thirds of this area is now denuded and charcoal has risen to prohibitory prices. There is a limited amount of brown and spathic ores, the latter in the best

beds averaging about 50 per cent. of iron, giving 59 per cent. in the roasted ore. The silica is 10 per cent. The home supply of raw material is so poor that coke is brought 350 miles from the Donetz basin, and ore from the Krivoi Rog and Kertsch, the distance for the latter being about 600 miles. The recent depression in the Russian trade seriously affected this district, the large furnaces at Lipetzk and other smaller plants being closed down at the end of 1901. The Vyksa and Shipov works, however, increased their output during the year.

SEC. XXVIf.—*The North:*

The district of North Russia includes the province of Petersburg, Olonetz and Courland. There are some depósits of magnetites and lake ores, and works have been operated for a long time, using charcoal as fuel. The present output of ore and pig-iron is small, but by the importation of fuel and pig-iron, mostly from England, a considerable amount of steel is made.

TABLE XXVI-D.

Imports at St. Petersburg in 1899.

	Tons.
Pig-iron	9,000
Coke	128,000
Coal	1,639,000

There are several works of some size in the north, the Poutiloff, Nevski, Alexandrovsky, Kolpino and Obeuhoff being in the neighborhood of St. Petersburg. The Poutiloff is the largest, having two converters and twelve open-hearth furnaces. Another works, the Petrozavodsk, is situated one hundred miles away at Ladogua.

CHAPTER XXVII.

AUSTRIA-HUNGARY.

This chapter was reviewed by the late Ernest Bertrand who was general manager at Kladno and by the late Carl Sjögren, who was engineer at Donawitz.

SECTION XXVIIa.—*General View:*

The steel production of Austria demands attention on account of the energetic way in which improvements have been made in recent years, and because her metallurgists have always been progressive. As far back as November, 1863, acid Bessemer steel was made at Turrach, in Styria, and this was followed in the next year by Neuberg, and by eight others soon afterwards. The Thomas Gilchrist basic Bessemer process was ushered into the world in 1878 and only one year later the first charge was made at Kladno, in Bohemia. In the same year both Teplitz and Witkowitz adopted the practice.

The steel industry of Austria exists in three districts shown in Fig. XXVII-A: Moravia and Silesia in the north and east; Bohemia in the northwest, and Styria and Carinthia in the southwest. Not one possesses all the essentials for cheap production, for Bohemia and Styria have no coke, and Moravia no ore. Moreover, the

TABLE XXVII-A.

Approximate Annual Output of Fuel, Ore, Iron and Steel in Austria-Hungary; tons.

Province.	Bituminous Coal.	Lignite.	Ore.	Pig Iron.	Steel.
Bohemia	3,600,000	18,260,000	680,000	280,000	210,000
Styria	.....	2,590,000	1,210,000	300,000	250,000
Moravia	1,480,000	190,000	10,000	280,000	235,000
Silesia	4,700,000	.....	.....	60,000	
Gallicia	1,170,000	80,000	.....	.....	.....
Hungary	1,240,000	4,290,000	1,570,000	420,000	350,000
Other provinces	40,000	1,000,000	70,000	50,000	90,000
Total	12,230,000	26,410,000	3,540,000	1,380,000	1,135,000

situation of Austria does not facilitate international trade, especially as Russia has a decided protective tariff system. For this reason the Austrian industry is not specialized and cannot tend toward a heavy

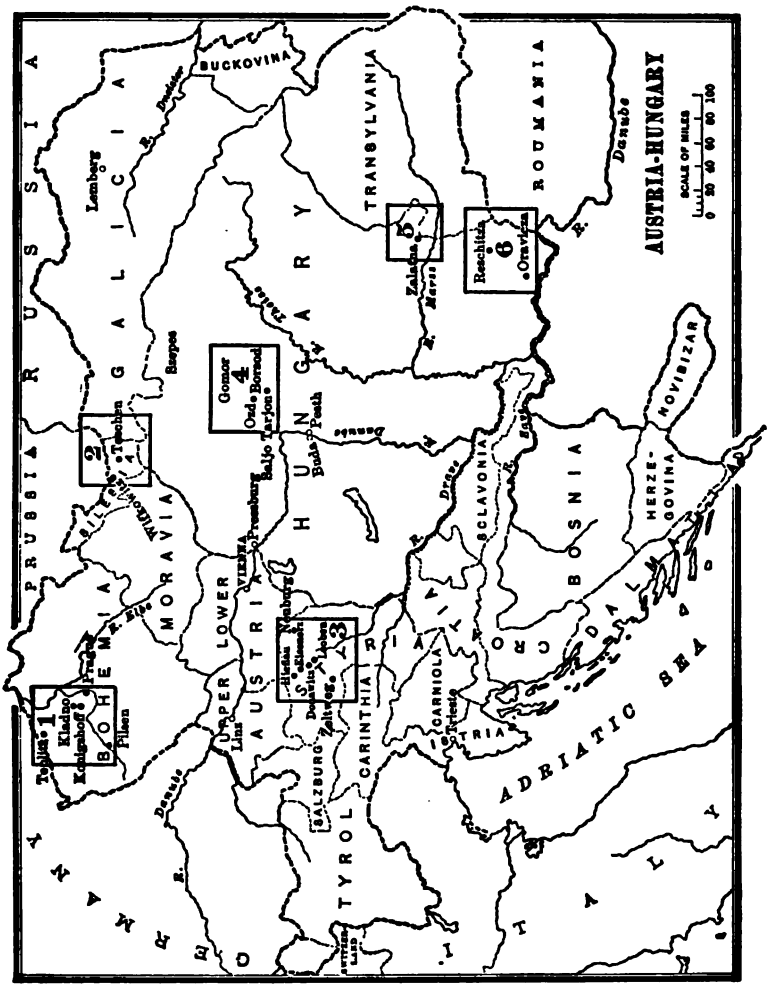


FIG. XXVII-A.

production of one line of work, but toward a diversified output, and for this reason also the basic open-hearth is becoming the general method of manufacture. A considerable amount is made by the basic Bessemer, but very little by the acid open-hearth, while during January, 1901, there was blown what will probably be the last

heat of acid Bessemer steel. The statistics of production are given in Tables XXVII-A and XXVII-B, the latter showing how the basic process has supplanted the work on acid linings.

TABLE XXVII-B.

Production of Steel in Austria (not including Hungary).

Year.	Bessemer Steel.			Open Hearth Steel.			Total Steel.
	Acid.	Basic.	Total.	Acid.	Basic.	Total.	
1879	76,848	3,500	79,848	19,697	.....	19,697	99,545
1880	75,027	17,835	92,862	20,481	.....	20 481	113,343
1881	88,279	31,889	120,168	29,846	.....	29,846	150,014
1882	101,230	57,714	158,944	39,740	.....	39,740	198,684
1883	101,254	88,429	189,683	43,797	.....	43,797	233,480
1884	86,855	70,987	157,842	40,009	.....	40 009	197,851
1885	88,288	76,821	165,109	41 021	.....	41,021	206,130
1886	60,016	105,839	165,855	25.861	11.204	37,065	202 920
1887	67,620	118,379	185,999	18.809	29,631	47,940	233,939
1888	76,533	139,127	215,660	25,572	50,962	76,534	292,194
1889	72,849	126,508	199,351	82,121	77,516	109 637	308,988
1890	76,684	103,180	179,864	29,204	133,808	163,012	342,876
1891	60,718	95.061	155,774	27,800	150,498	178,298	334,067
1892	50,379	100.841	151,220	20,114	180,951	201.065	352,285
1893	48,657	108.104	156,761	19,794	203,894	223.688	380,449
1894	47,784	133,131	180,915	17,729	254,835	272,564	453.479
1895	46,502	127,816	174,318	18,576	304,747	323,323	497,641
1896	46,931	157.216	204,147	21,587	356,973	378,560	582,707
1897	38,713	167,688	206.401	14,764	405.098	419,852	626,253
1898	41,963	184,650	226,613	15.952	480.125	496,077	722,690
1899	38,538	186,643	225,181	18,314	540,894	559,208	784,389
1900	18,214	182,809	201,023	23,196	557,110	580,306	781,329

Owing to the high freight rates and the long distances from the northern coal districts to the southern parts of the Empire a large quantity of coal is imported at southern ports. In the year 1899 the total coal raised was 41,000,000 tons, but only 11,450,000 was bituminous, the remainder being lignite. In the same year the imports amounted to 17,000,000. The gas works at Trieste sells coke for domestic use at $9.30 per ton. A large quantity of Westphalian coke is brought to the blast furnaces of Bohemia and even to Styria, since the coke districts of Moravia and Silesia are unable to meet the demand. There is one large blast furnace at Trieste which uses coke from England and sometimes ocean-borne coke from Westphalia, and the smaller charcoal furnaces in the south often use a certain proportion of imported coke. The total production of coke in Austria in 1900 was 1,227,918 tons, almost all in Moravia and Silesia. The production of Hungary was only 10,000 tons.

To balance the considerable quantities of coke coming into Austria from Germany, there are large amounts of brown coal (lignite) carried from Bohemia into Germany. It goes northward by water transports on the Elbe to Magdeburg, and even to Hamburg, meeting there the competition of English and Westphalian fuel.

SEC. XXVIIb.—*Bohemia (see No. 1 on Map):*

This province is well supplied with fuel, although there is no good coking coal. It raises nearly four million tons of soft coal each year and eighteen million tons of lignite, most of the latter coming from the vicinity of Teplitz. Bohemia also has a supply of iron ore well suited for the basic Bessemer. It carries from 0.6 to 0.8 per cent. of sulphur and is roasted and leached with water to dissolve the sulphates, after which treatment it averages about as follows:

	Per cent.
Fe	42.00 to 48.00
P	1.2
Mn	0.1
S	0.3

The coke is brought from Silesia and Westphalia. The principal works are those of the Prager Eisen Industrie Gesellschaft at Kladno and Teplitz, and the Böhmische Montan Gesellschaft at Königshof. Kladno has four modern blast furnaces, three basic converters of 13 tons capacity, a basic open-hearth plant and mills for rolling rails, structural shapes, wire, etc. The blooming mill is strong and ingots of three tons are rolled into rails and beams in one heat. Teplitz has three basic converters, two heavy plate mills and a beam mill. It receives pig-iron from Königshof, where there are four modern blast furnaces and one basic converter. Until recently there was considerable business done in small ingots only four inches square, which were rolled directly into small shapes, but this practice is now carried on only at Königshof and in small amount. It is found more economical to roll billets from large ingots than to cast small pieces, this being the trend of experience throughout Europe. It is at Kladno that Mr. Bertrand developed the Bertrand Thiel open-hearth process discussed in Chapter XII. The ore used in the open-hearth furnaces is partly Gellivare (Swedish), and some of this is also used in the blast furnace to reduce the content of phosphorus in the pig-iron to about 1.5 per cent.

It is also necessary to mention the steel-casting plant of the Skoda Company at Pilsen, which has a high reputation for difficult stern posts, etc., for large ships, and is equipped with hydraulic presses for guns and armor. Table XXVII-C gives a list of the principal works in Bohemia.

TABLE XXVII-C.

List of Steel Works in Bohemia (Böhmen).

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Prager Eisenindustrie...	Kladno	.....	3	.....	2	160,000
	Teplitz	.....	3	.....	.....	
Boemische Montan, etc.	.....	.....	2	.....	.....	40,000
Skoda Steel Works.	Pilsen	.....	.....	4	.....	14,000

SEC. XXVIIc.—*Moravia and Silesia (see No. 2 on Map):*

The coal field already described as covering a large part of upper German Silesia extends into Austrian Silesia and Moravia. The coal is rich, but does not give the best of coke. Immediately around Ostrau, where Witkowitz is situated, the quality of the coke is fair, but in Silesia it is poor. It is, however, the only coke district east of Westphalia, and forms the nucleus for a considerable iron industry. The coke is used not only in Moravia, but in Bohemia, and is shipped across the Russian frontier to the blast furnaces in Poland, which are almost entirely dependent upon this district for their supply. The Styrian steel works has lately bought coal properties in the Polish Moravian district and will make coke at the mines for its furnaces in the southern district. The relative importance of the Silesian coal district as it affects the different nations will be seen from Table XXVII-D.

TABLE XXVII-D.

Output of the Silesian Coal Field.

	Tons in 1899.
Germany; Silesia	23,527,000
Austria; Moravia and Silesia.....	6,252,000
Russia; Poland	3,965,000

The province of Silesia produced three times as much coal as Moravia, but the latter division made the most coke, as the southern portion seems to give the best material for smelting. The predominant iron and steel producer in this region is the works at Witkowitz in the province of Moravia. This plant draws much of its ore from its own mines in Hungary, the deposit being a carbonate, which is roasted. It makes about one-quarter of all the pig-iron that is made in Austria, the output being about 25,000 tons per month. There are six blast furnaces and two acid-lined converters and eight twenty-ton basic open-hearth furnaces, which are operated by the duplex process, the pig being first blown in an acid converter, and then transferred to a basic open-hearth furnace. The pig is of the following composition: Si, 1.2; Mn, 2.7; P, 0.2; C. 3.7. It is evident that the charge could not be finished in a basic converter, owing to the low content of phosphorus, but after the oxidation of the silicon and most of the carbon the time in the open-hearth furnace is reduced to about three hours. Under this practice only a small proportion of ore is needed in the open-hearth furnace, a matter of considerable importance at Witkowitz, as good lump ore must be brought from Sweden. It may also be considered that the blast furnace is not confined to narrow limits of silicon, as in basic practice. The slags from the acid converter and the basic hearth run as follows:

Slags from Duplex Process at Witkowitz.

	Converter.	Open Hearth.
Fe	6.75	18.03
Mn	26.27	7.33
SiO_2	50.24	15.10
Al_2O_3	6.06	2.89
CaO	1.49	37.10
MgO	0.23	7.50
P_2O_5	0.04	4.05

The works produces large quantities of all forms of rolled steel and has a large steel-casting plant. In the coal region of Silesia are the works at Trynietz, with two acid converters and seven basic open-hearth furnaces, and mills for rails, structural shapes and merchant iron. Table XXVII-E gives the principal works in Moravia and Silesia.

TABLE XXVII-E.

List of Steel Works in Moravia (Mähren) and Silesia (Schlesien).

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Witkowitz Bergbau, etc..	Witkowitz	2*	.....	.....	8*	150,000
	Witkowitz	.....	.....	.....	4	25,000
Archduke, Frederic.....	Teschen ...	2	.....	.....	7	60,000

SEC. XXVIId.—*Styria (see No. 3 on Map):*

A journey to a steel plant is not usually looked upon as a pleasure from an æsthetic point of view, but there is one exception in a visit to the beautiful valley where the ancient town of Leoben and the steel works of Donawitz lie peacefully hidden in the shadow of the Alps. At the end of the valley, only a few miles away, is a mountain towering in a huge cone nearly 5000 feet above the sea and 3000 feet above the hamlet below. This is the Erzberg or Ore Mountain. The whole surface is a layer of spathic ore from 200 to 500 feet thick and it is mined by a succession of terraces all the way up the mountain side.

This deposit has been known from most ancient times, the present province of Styria being a part of the Roman province of Noricum, from whence came a large portion of the weapons of the Roman legions and other iron instruments of the Empire. In fact, Styria and Carinthia both claim the "rather doubtful honor" of supplying the nails for the cross upon Calvary. Certain it is that the mines were worked tens of thousands of years before that, for the remains of primeval man have been found beside the unburned charcoal of prehistoric forges.

A modern plant of blast furnaces has been built at Eisenerz, near the Erzberg, and during 1902 the output per furnace was upwards of 450 tons per day of white pig, with a consumption of 1900 pounds of coke per ton of iron. The ore is a carbonate of about the following composition:

The ore is roasted in kilns, giving 50 per cent. in iron. It is smelted with coke from Westphalia and Austrian Silesia, the first

* These converters and furnaces are worked by the "combined" or "duplex" process.

I.	Crude.	Roasted.
FeO	34.97	.....
Fe_2O_3	16.75	74.04
Mn_3O_4	2.98	4.01
SiO_2	8.20	11.04
Al_2O_3	2.09	2.81
CaO	3.06	4.12
MgO	2.92	3.93
CO_2	27.60	.....
P_2O_5	0.04	0.05
SO_3	tr.	.....
	98.61	100.00

II.	Crude.	Roasted.
Fe	38.93	51.80
Mn	2.15	2.84

being 500 miles away in a straight line. The transportation is expensive from both fields, owing to the heavy grades on the picturesque route through the Steiermark Alps.

Many blast furnaces of Austria are built upon a plan which is different from the usual American construction. The whole structure rests not upon solid ground, but on a pier formed of arches, so that one may walk underneath the bottom. At Donawitz the taphole is fifteen feet above the general level. The mere elevation is nothing unusual, as many American furnaces are built high in the air to allow the iron and slag to be carried away in cars, but in Austria it is claimed that the bottom of the furnace must be kept cool, in order to prevent the cutting away of the lining and the breaking out of the iron. This difference in construction is due very much to a difference in the work to be done. When running on ordinary Bessemer iron for the acid converter, the temperature is high, and graphite is deposited as a protective covering in the interior of the hearth; but when low-silicon iron is desired, the conditions are quite the reverse. It is safe to say that no American furnaceman will agree to make iron regularly with as low a content of silicon as the standard product at Donawitz. I have been given the following as typical:

C	4.00
Si	0.10 to 0.30
S	tr to 0.03
P	0.08 to 0.10
Mn	2.0 to 2.5

This iron is taken to a basic open-hearth furnace in a molten state, and the value of the low silicon need not be dwelt upon. The linings are of magnesite, for in Styria this mineral is as cheap

as almost any other refractory material. Taken all in all, it may be considered a fortunate thing for the rest of the world that good coking coal does not exist in the Steiermark.

There is a deposit of brown coal near by, and Styria in 1899 raised 2,624,000 tons, or about ten per cent. of the total output of Austria. It is the only province besides Bohemia that does produce a large quantity, but there is no bituminous coal found in the Empire, except in the northern provinces. The predominant steel producer in the district is the Alpine Montan Gesellschaft, and mention has already been made of the furnace plants smelting the ore of the Erzberg. The one great steel works is at Donawitz, near Leoben, which has lately been entirely rebuilt. There are also modern plate and universal mills at Zeltweg. Table XXVII-F gives a list of the principal works in Styria.

TABLE XXVII-F.

List of Steel Works in Styria (Steiermark).

This district is marked on the map as No. 8.

Name of Plant.	Location.	No. of Bessemer Converters.		No. of Open Hearth Furnaces.		Annual Output; tons.
		Acid.	Basic.	Acid.	Basic.	
Oesterreichische.....	Donawitz..	.....	.....	.....	13	160,000
Alpin Montan, etc.....	Neuberg...	.....	.....	3	2	20,000
	Zeltweg....	.....	.....	.....	2	25,000

SEC. XXVIIe.—*Hungary:*

The iron industry of Hungary is scattered, but half of all the pig-iron is made in the northern portion in the counties of Szepes, Gomor, Borsod and their immediate neighborhood. Considerable ore is found in this district, the deposit being a spathic carbonate which must be calcined. In 1899 there were 1,337,000 tons of ore raised in this field, about 30 per cent. of this being exported. The works at Witkowitz in Moravia owns mines here, and in 1899 took 200,000 tons of ore from Borsod county, which was nearly all it produced, while a considerable quantity is sent from other mines to Bohemia and German Silesia, the works at Friedenshütte owning mines near Kotterbach. Out of 67 blast furnaces in Hungary there are 37 in this Szepes Iglo district. Most of them are small, some

use charcoal, but many bring coke from Silesia, as good coking coal is not found in any part of Hungary.

There is a considerable steel plant of the Rimamurian Salgo Tarjan Ironworks Company at Salgo-Tarjan, this company owning mines in Gomor county and having blast furnaces and rolling mills. About 75,000 tons of steel are made per year from three 7-ton basic converters. There are also smaller works at Ozd, while the Austrian-Hungarian State Railway operates two basic converters and several open-hearth furnaces, making together about 50,000 tons per year. Another small Bessemer plant is at Sohl. In the South is the old-established plant at Reschitza, where there are three basic converters and three 20-ton open-hearth furnaces with a capacity of 40,000 tons per year. The iron for this is made in the immediate neighborhood.

These two districts in the North and in the South make three-quarters of all the pig-iron smelted in Hungary and a larger proportion of the steel. The only other district worth mentioning is in the southeast in Transylvania, where a larger amount of pig-iron is made than in Reschitza. The great drawback throughout Hungary is the absence of coking coal, and only 10,000 tons are produced per year, this being made in the vicinity of Buda Pest. The Hungarian works, therefore, are on a moderate scale, and being protected by the Government in every way content themselves with supplying the wants of the State railways and of the general

TABLE XXVII-G.

Production of Coal, Ore and Pig-Iron in Hungary in 1899.

	Szepes-Iglo (Northern Part).	Zalatna (Transylvania).	Orvicza (Southern Part).	Budapest.	Others.	Total
Designation in Pl. XXVII-A.	4	5	6			
Active blast furnaces	32	9	7	.....	6	54
Idle blast furnaces	5	2	2	.....	4	13
Pig Iron	259,698	107,575	76,060	.....	8,314	451,647
Iron Ore	1,337,451	270,882	135,793	186,280	22,823	1,567,860
Bituminous Coal	.....	7,648	470,018	761,189	.....	1,238,855
Coke	.....	.....	.....	10,086	.....	10,086
Lignite	.....	785,010	53,819	1,883,114	1,570,641	4,292,584

home market. Table XXVII-G gives the output of fuel and iron in 1899, while Table XXVII-H gives the steel production.

TABLE XXVII-H.

Production of Steel in Hungary.

Year.	Bessemer Steel.			Open Hearth Steel.			Total Steel.
	Acid.	Basic.	Total.	Acid.	Basic.	Total.	
1880	12,854	.....	12,854	8,021	.....	8,021	20,875
1885	61,269	.....	61,269	11,384	.....	11,384	72,653
1886	51,106	.....	51,106	3,201	2,740	5,941	57,017
1887	47,163	.....	47,163	4,199	13,891	18,090	65,253
1888	72,687	.....	72,687	3,100	24,832	27,932	100,619
1889	60,152	14,914	75,066	3,800	28,658	32,458	107,524
1890	72,976	34,841	107,817	4,700	44,207	48,907	156,724
1891	57,475	41,262	98,737	525	52,709	53,234	151,971
1892	54,030	45,448	99,478	.....	59,380	59,380	158,858
1893	68,493	51,313	119,806	.....	69,421	69,421	189,227
1894	69,968	57,496	127,464	.....	79,483	79,483	206,947
1895	80 579	65,518	146,097	.....	100,809	100,809	246,906
1896	73,172	66,542	139,714	1,413	153,563	154,976	294,690
1897	66,567	65,778	132,345	3,529	176,436	170,965	303,310
1898	66,081	71,310	137,391	4,298	189,862	194,160	331,551
1899	41,894	62,136	104,030	2,410	226,195	228,605	332,635
1900	49,842	62,336	112,178	11,387	229,199	240,586	352,764

CHAPTER XXVIII.

BELGIUM.

This article has been submitted to M. H. de Nimot, secretary of the Association des Maitres des Forges, at Charleroi, Belgium. M. de Nimot objects to my statement that the working people of Belgium are "bound to the vocations of their fathers." I deem it justice to him to offer his protest, but I believe that the argument herein given portrays a real difference between the workmen of Belgium and America.

Belgium is essentially a fuel-producing country. In 1900 she raised 23,462,817 tons of coal, which is about one-tenth of the production of the United States or of Great Britain. The production of coke was 2,434,678 tons. Table XXVIII-A shows that three-fourths of all the coal and coke comes from the province of Hainaut on the border of France, and the remainder from Liège. The Belgian coal mines have reached a great depth, which increases the cost of operation, and there is much trouble from gas in the beds, causing fearful explosions which no care can prevent. The average working depth in Hainaut is 1600 feet, while some mines run from 3400 to 3800 feet. It is estimated that the coal will last from one hundred to two hundred years, this period being the same as that assigned to the deposits of Central France, the North of England and Central Bohemia.

The average cost of coal at the mines for the whole country for 1899 was officially given at 10.72 francs=$2.07 per ton, and the average selling price $2.40. In 1900 the cost was $2.78 and the selling price $3.48. The average price of coke was $3.96 at the ovens in 1899, but in 1900 the price averaged $4.18, although blast furnace coke was sold at an average of $3.40 per metric ton. One-fifth of all the coal raised, and over one-third of all the coke made, is exported, most of these shipments going to France. On the other hand, the imports of coal amount to one-seventh as much as is raised, and a considerable quantity of coke is brought in, these imports coming from Westphalia across the eastern border, while the exports go southward. The Westphalian coke is superior to the

Belgian product, but it is economical for the French works to buy the poorer article, on account of the short haul.

TABLE XXVIII-A.

Production of Coal, Coke, Iron and Steel in Belgium in 1900.

	Hainaut.	Liège.	Namur.	Luxemburg.	Total.
Coal raised	16,532,630	6,190,892	739,295	.....	23,462,817
Imported from Germany	.....	.....	.....	.....	1,573,697
" " England	.....	.....	.....	.....	1,173,917
" " France	.....	.....	.....	.....	497,088
Exported to France	.....	.....	.....	.....	3,917,765
Coke made	1,748,450	686,228		.....	2,434,678
Imported from Germany	.....	.....	.....	.....	220,758
" " England	.....	.....	.....	.....	40,559
" " France	.....	.....	.....	.....	25,668
Total exports	.....	.....	.....	.....	1,073,313
Exported to France	.....	.....	.....	.....	646,369
Ore raised	.....	.....	.....	247,890	247,890
Imported from Luxemburg	.....	.....	.....	.....	1,564,579
" " Spain	.....	.....	.....	.....	321,478
" " France	.....	.....	.....	.....	291,788
" " Sweden	.....	.....	.....	.....	98,539
" " Others	.....	.....	.....	.....	252,236
Pig iron made	.....	.....	.....	.....	1,018,561
Imported from England	.....	.....	.....	.....	155,873
" " France	.....	.....	.....	.....	73,603
" " Germany	.....	.....	.....	.....	53,674
" " Un. States	.....	.....	.....	.....	12,259
Steel made	225,945	429,254	.....	.....	655,199
Rails	.....	.....	.....	.....	134,438
Puddled iron	.....	.....	.....	.....	333,981
Finished iron	.....	.....	.....	.....	358,163
Exports of finished iron & steel	.....	.....	.....	.....	415,808
Total number of blast furnaces	16	17	.....	6	39
Active in 1901	8	12	.....	5	.....
Number of Bessemer converters	.....	.....	.....	.....	47
Number of open hearth furnaces	.....	.....	.....	.....	18
Av. wage in steel works per day	77 cents	78 cents	.....	.....	.....

Belgium formerly raised a considerable quantity of iron ore, but her maximum production was reached in 1865 with a total of 1,019,000 tons, the output since then having decreased until now it is only one-fifth of that amount. Some ore is raised in the province of Luxemburg, which touches the great Minette deposit that spreads out over the adjoining Grand Duchy of Luxemburg, now in commercial alliance with the German Empire. It is from the Grand Duchy and from Rhenish Prussia that Belgium draws most of her ore, although a considerable amount is brought from Spain to Liège, very little foreign ore going elsewhere in the country except some containing manganese. The pig-iron from these Spanish ores makes one-sixth of all the iron produced in Belgium, and is used for acid Bessemer steel. The ores from the Minette district give an iron running from 1.3 to 2 per cent. in phosphorus

and large quantities are used for puddling and foundry purposes. In making iron for the basic Bessemer it is a common practice to use a certain proportion of manganiferous ores and slags, so that the iron will contain from 1.5 to 2 per cent. of manganese.

The pig-iron used in Belgium is of domestic manufacture, about one-sixth of the total output being made in the province of Luxemburg, the remainder being equally divided between Liège and Hainaut. The total production of the country at its maximum is one million tons per year or about what would be made by ten furnaces making three hundred tons per day. Three-quarters of all the pig-iron is smelted at eight plants, a list of which is given in Table XXVIII-B.

TABLE XXVIII-B.

Important Blast Furnace Plants in Belgium.

Province.	Name of Works.	Location.	Number of Blast Furnaces.	Capacity per Furnace per Day.
Hainaut	la Providence	Marchienne	3	.....
	de Coullet	Near Charleroi	4	90
	de Monceau Sur Sambre	Near Charleroi	2	90
Liège	Soc. John Cockerill	Seraing	6	.....
	L'Esperance Longdoz	Seraing	2	.....
	Angleur	Tilleur	4	.....
	Ougrée	Ougrée	4	.....
Luxemburg	d'Athus	Athus	2	70

The steel is made in the two provinces of Liège and Hainaut. The production in 1899 was 718,000 tons or 60,000 tons per month, but in 1900 this fell to 655,000, while in 1901 it was 500,000 tons, owing to the depression in business throughout Europe. Out of 47 converters only 25 are in operation and only 12 open-hearth furnaces are working in the whole country. Over 60 per cent. of the steel was made at Liège, and the works of John Cockerill made most of the rails that were rolled, amounting in 1900 to 134,000 tons, or 11,000 tons per month.

The advantages possessed by Belgium are the short distances through which material must be carried. A circle of a hundred miles radius takes in the coal and ore mines and a seaport, while the average haul is much less. The wages of labor are low, and although it is a common saying that a man works just in proportion to the way he is paid, this saying is not always exact. A man

working for 60 cents a day in Liège does not do as much work as an American laborer receiving twice as much, but it does not follow that he is only half as efficient. A woman loading coke and ore buggies for 30 cents a day may not do the work done by a buggy-puller in Pittsburgh receiving six times as much pay, but it does

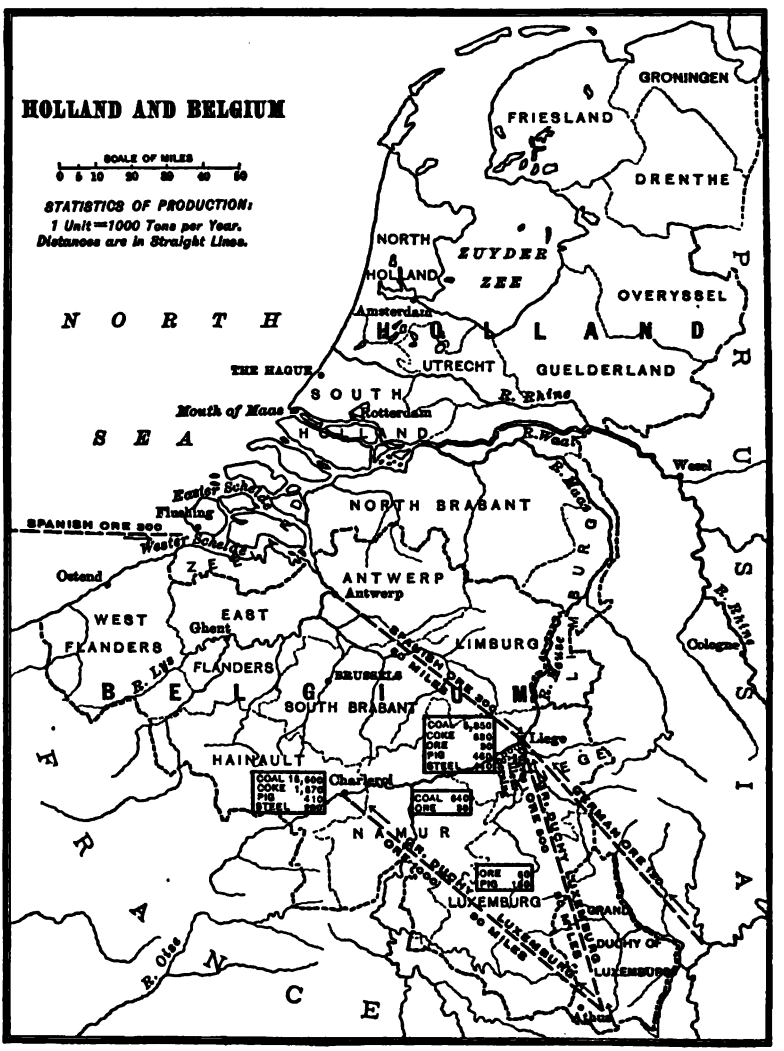


FIG. XXVIII-A.

not follow that she only does one-sixth as much. There is a large profit for the manufacturer, particularly in the great number of cases where some human intelligence and some human hand must be at a certain post, and where the grade of the intelligence and the strength of the hand are of little moment. There are multitudes of positions in a steel works where this condition obtains, and in Belgium women fill such positions, receiving a mere pittance. They do a very large share of the work that we call "general labor." About ten years ago Belgium passed laws regulating the employment of women and children in mines, and there has been a marked advance in this direction. In 1870 there were from 8000 to 9000 women and girls working underground in the coal mines. In 1889 there were 3700. In 1891 the women and girls constituted four per cent. of all the working force under ground, while in 1899 they formed only a fraction of one per cent. Of the over-ground workers the women and girls constituted 25.1 per cent. in 1891, 24.3 per cent. in 1899, and 23.1 per cent. in 1900. Of the over-ground workers at these mines in 1900, in a total of 34,075 people, there were 3787 girls between the ages of 16 and 20, or 11.1 per cent. of the whole. In addition to these there were 2589 girls between 14 and 16, a proportion of 7.6 per cent., so that 18.6 per cent. of the entire force was made up of girls between 14 and 20 years of age.

Considering the works above and below ground together for the year 1899, concerning which I have the full official statistics, there was a total of 125,258 people, of whom there were 6522 girls from 14 to 20 years of age, or 5.2 per cent. A little calculation from the mortality tables will show that this represents over half of all the girls of that age that would be found in a community containing that number of people, and after allowing for the infirm it will be seen that in the coal-mining communities of Belgium almost all the girls between the ages of 14 and 21 work around the coal mines or coke ovens.*

It is difficult for an American to appreciate what this means until he sees the conditions on the spot and until he has known what it is to work day and night shift out doors in all weather and in all seasons. It seems inevitable that the same law of

* I have calculated these figures from the official report of the Directeur General des Mines for 1899.

progress which has led Germany to abolish woman labor in steel works, which emancipated woman in England a generation ago, and which never allowed her to consider drudgery in America, will extend its power over Belgium and Austria. When this happens the wages of men must be increased, as there will be but one wage-earner in the household.

The spread of general intelligence will also have its effect upon the remote districts. At present the working-classes in many places seem bound to their home and to the vocation that their fathers knew before them. This is a sort of mediæval and provincial idea not entirely absent in other parts of Europe, and it may even be detected in America, but in England and in the United States it cannot be reckoned with in the labor situation. These ideas must disappear and with them will disappear the cheap labor of Belgium, although all history shows that an increase in the wages of the day laborer need not necessarily raise the cost of manufactures.

In addition to her production of steel, Belgium turns out a large quantity of puddled iron. In the year 1900 her production of steel was 655,000 tons and of wrought-iron 358,000 tons, a great deal of the latter being exported in the form of structural shapes. Belgium covers an area of only 11,370 square miles and had a population in 1899 of 6,744,532, so that her output of steel and wrought-iron is greater per inhabitant than any other nation. As a result she must seek an outlet, and her exports of iron and steel wares amount to nearly one-half her production. The actual tonnage shipped, however, is comparatively small, being only one-quarter of the exports of Great Britain.

The area of Belgium is only one-fourth that of Pennsylvania, but if we take the southwestern part of the latter State, comprising the coke and iron districts in the counties of Allegheny, Westmoreland and Fayette, and as far east as Indiana, Cambria and Blair, we find that this section of the State, though having the same number of square miles as Belgium, contains less than one-fourth of her population. Or if we take the most thickly settled three States in the Union—the New England States, Massachusetts, Rhode Island and Connecticut—these three have an area thirty per cent. greater than Belgium and yet have only half the population. These figures give some idea of the density of population in this ancient State.

CHAPTER XXIX.

SWEDEN.

I am indebted to my friend, Hjalmar Braune, metallurgical engineer of the Mining School at Filipstad, who has carefully read, corrected and twice reread the manuscript I have also consulted the Swedish official publication, *Kommerscollegii berättelse, for 1900* for the data in Table XXIX-A and Fig. XXIX-A. Much information has been taken from *L'Industrie Miniere de la Suede, 1897*, by Nordenström, and the paper by Akerman in the Journal of the Iron and Steel Institute for 1898.

Compared with the greater nations, the steel turned out by Sweden is of little importance when measured by tons, but she cannot be omitted from special consideration, on account of her increasing importance, as a source of iron ore, on account of the ancient prestige of her products, and the care and skill with which that prestige is maintained.

TABLE XXIX-A.

Production of Iron and Steel in Sweden in 1900 and 1901; tons.

	South 1900.	Southeast 1900.	Centre 1900.	North 1900.	Total 1900.	Total 1903.
Coal	250,000	.....	.....	.....	250,000	320,000
Ore	.....	1,000	1,563,000	1,044,000	2,608,000	3,678,000
Pig	.....	24,000	503,000	.....	527,000	489,700
Wrought Iron	.....	23,000	165,000	.....	188,000*	191,300
Bessemer Steel	.....	.....	91,000	.....	91,000	84,800
Open hearth Steel	.....	19,000	188,000	.....	207,000	225,200
Total Steel	.....	19,000	279,000	.....	298,000	310,000

* The classification of wrought-iron products is imperfect and the figures inaccurate.

The chief characteristic of Sweden in the iron industry is her lack of coal and her supply of forests. It is a safe assertion that had coal existed in Sweden to any extent the manufacture of iron would be far greater, but her steel would never have achieved its present reputation. There are two or three ore beds of exceptional purity, as far as phosphorus is concerned, and the fame of Swedish

iron rests on these deposits at Dannemora, Norberg and Persberg. Charcoal contains no sulphur, and if the ore, after roasting, con-

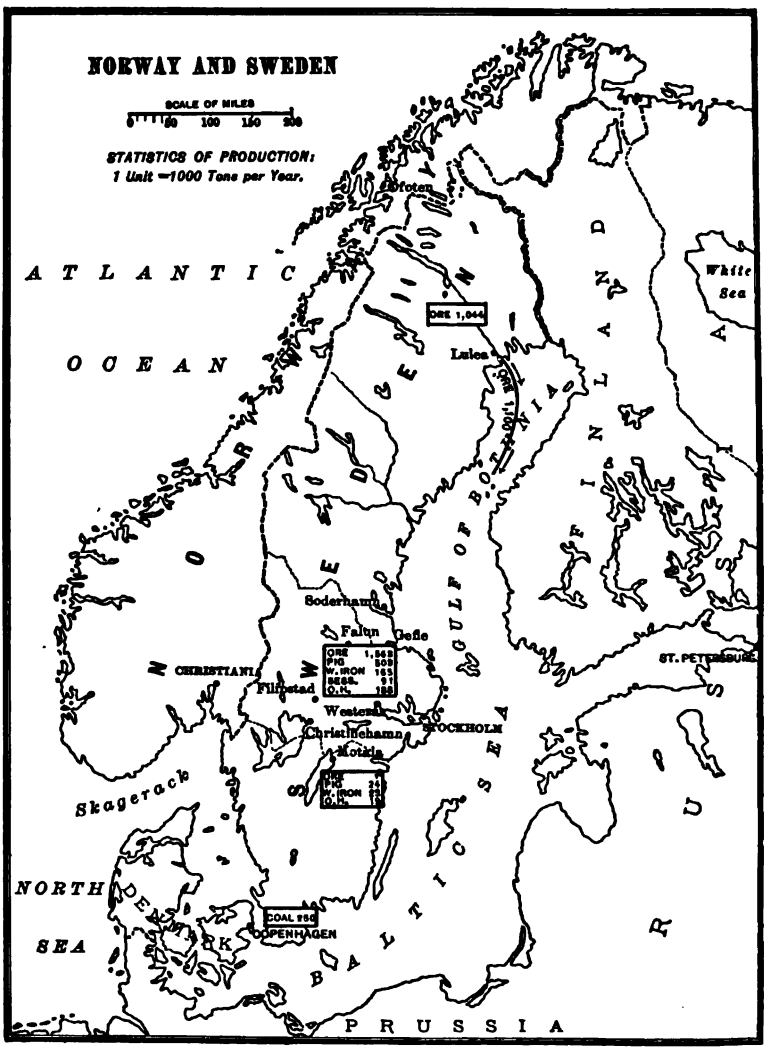


FIG. XXIX-A.

tains none the pig-iron can contain none, even though the blast furnace be working cold. This is a proposition rather startling,

but decidedly attractive to the average furnaceman, and it is the foundation of the reputation of Sweden.

Up to the year 1895 Sweden produced more wrought-iron than steel, but since then the output of iron has remained stationary, while the output of steel has increased. Ninety per cent. of this iron is made on the Swedish Lancashire hearth, an improved form of the ancient device, wherein a mass of pig-iron is caused to melt on the top of a charcoal fire and the melted mass again brought to the top and remelted, all the time being exposed to the blast, by which the silicon, manganese and carbon are eliminated under the influence of a slag of about the following composition: SiO_2=10 per cent.; FeO=78 per cent.; Fe_2O_3=12 per cent. This gives the softest product that can be made by any steel or iron-making process, and when a charcoal pig-iron, low in phosphorus, sulphur, manganese and silicon, is used with charcoal, the latter being free from phosphorus and sulphur, the product must necessarily be pure.

In order to get the proper kind of pig-iron, it is necessary to have an ore free from phosphorus. The usual Swedish ore is a hard magnetite; the blast furnaces are small, ranging from 40 to 60 feet in height and 7 to 10 feet bosh, with a diameter at the tuyeres of from 3.5 to 6.5 feet. When making pig for the Lancashire hearth the blast is kept between 200° C. and 300° C. (390° F. and 570° F.), in order to keep the furnace cool; a diameter of over five feet at the tuyeres is not good practice, for a larger diameter, even with cold blast, will produce so high a temperature that manganese and silicon will be reduced. A drawing of a Swedish blast furnace for making pig-iron for the Lancashire hearth is shown in Fig. XXIX-B. The pig-iron used in the Lancashire hearth runs about as follows, in per cent.:

Si	0.10 to 0.50, usually 0.25 to 0.30
Mn	0.10 to 0.30
P.	0.01 to 0.03
S.	0.00 to 0.02

The composition of a very soft Lancashire wrought-iron, used for electrical purposes, is as follows, in per cent.:

C	0.05—0.06
Si	0.023
Mn	0.03
P.	0.025
S	0.005

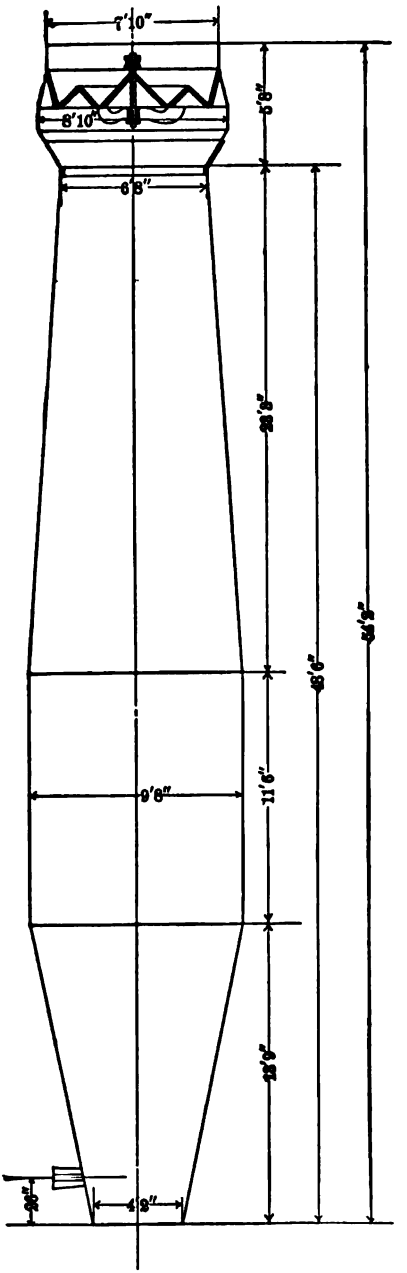


FIG. XXIX-B.—SWEDISH BLAST FURNACE.

In making Bessemer iron a higher temperature is allowable and the diameter may be 6.5 feet, at the tuyeres, and the blast may be from 400° C. to 500° C. (750° F. to 930° F.), but even under this practice, and still more surely in the making of pig for the Lancashire process, the temperature of the zone of fusion in the blast furnace is so low that sulphur cannot be eliminated in the slag, and it is, therefore, necessary to roast the ores, even though they contain but a small quantity of pyrite. This roasting changes the condition of the iron from Fe_3O_4 to Fe_2O_3, and thereby reduces the consumption of fuel in the blast furnace. In making Bessemer iron the aim is to get 1.00 per cent. silicon and from 1.50 to 3.00 per cent. manganese. The charcoal contains 85 per cent. of carbon, 3 per cent. of ash, and 12 per cent of moisture, and 600 to 1000 kg. of carbon are burned per 1000 kg. of pig-iron.

In 1897 there were 144 active furnaces, and allowing for the actual time in blast there was an average production of 13.1 tons per day. There were 130 works making wrought-iron and steel, and they averaged 12 tons per working day, which may give some idea of the scale of operations in Sweden. The average is no measure of the best, but in 1897 the largest blast furnaces were reckoned at 40 tons per day. In 1901 there were 139 blast furnaces giving an average daily product of 13.96 tons for the time they were in operation. In 1893 the production of Bessemer steel was 84,400 tons, being a trifle more than the open-hearth, which was 81,890 tons. The Bessemer output increased to 114,120 tons in 1896, but it is decreasing and in 1901 was only 77,231 tons, while the open-hearth product meanwhile steadily increased, until in 1900 it was 207,450 tons, there being a falling off in 1901 to 190,877 tons. During the year 1900 one-third of the Bessemer and one-fifth of the open-hearth steel was made by the basic process, the basic Bessemer being used in only one works. The production of crucible steel amounts to a little over 1000 tons per year.

Sweden exports large quantities of iron and steel, the proportion varying according to business conditions, but there has been a tendency for the proportion to be less as the growth of basic processes has enabled other nations to make the purer grades of metal. In 1840 she exported 86 per cent. of her wrought-iron and steel; in 1870, 62 per cent., and in 1897, 45 per cent. In 1890 the exports amounted to 225,000 tons and in 1897 to 210,000 tons. In 1900

she exported 356,080 tons of wrought-iron and steel, or 73 per cent. of her output, showing the effect of the general revival in the iron industry.

Having regard to the coal and iron industry alone, we may divide the country into seven parts. In the extreme south is the district of Malmöhus, which produces about 250,000 tons of bituminous coal per year, but this has no bearing on the iron trade. On the southwest is the district of Elfsborgs, where two open-hearth furnaces make 3000 tons of steel per year. In the immediate vicinity of Stockholm, in the districts of Stockholm, Upsala and Södermanland, a small quantity of ore is mined, and there are eighteen works producing 7 per cent. of the iron and steel output of the country. In the southern central portion, comprising the districts of Ostergötland, Jönköping, Kronoberg, Kalmar and Bleikinge, are 21 works making 8 per cent. A little north of Stockholm is the district of Gefleborg making 15 per cent.

The western central portion, including the district of Vermland, Orebro, Vestmanland and Kopparberg, is the great center of manufacture. This district in 1900, notwithstanding the great development in the extreme north in the Gellivare mines, raised 55 per cent. of all the ore produced in Sweden, nearly one-half of this coming from the mines at Grängesberg. This last-named ore runs 55 per cent. in metallic iron and .08 per cent. in phosphorus, and most of it is exported. It is in this region that the old mines of Dannemora, Norberg and Persberg are located, some of which have been worked for six and seven hundred years, and which have made Sweden famous for the quality of her products.

There are 56 iron works in this western central section, and in the year 1900 they made 74 per cent. of all the pig-iron and nearly 70 per cent. of all the iron and steel. There were 179 Lancashire hearths, 17 converters making a total of 58,392 tons in the year, and 34 open-hearth furnaces, making 156,110 tons of steel. The Bessemer converters averaged 3400 tons per year or less than 300 tons per month. The capacity of Swedish converters is from three to six tons. The iron is taken to them directly from the blast furnace and only three to five heats are blown per day.

To the outside world, one of the most important features of Sweden today is the exploitation of the great iron mines recently opened beneath the Arctic Circle. At present the Gellivare mines

are the only ones that are well developed. The ore is carried by rail to Lulea on the Baltic Sea or across Norway to Ofoten. This port, although so far north, is open all the year, while Lulea is inaccessible in winter. This railroad passes the great deposits of Kirunavaara and Luossavaara, where surveys indicate the existence of over 200,000,000 tons of ore above the water level. The Swedish Government has limited the amount for export to 1,500,000 tons per year. The ore runs from 57 to 70 per cent. in iron, the A grade being guaranteed between 67 and 70 per cent. with phosphorus below .05 per cent., but unfortunately there is comparatively little of this kind. The next class runs from 66 to 69 per cent. with phosphorus from .05 to .10 per cent., and so on down to the poorest with 57 to 61 per cent. of iron and 1.50 to 3 per cent. of phosphorus.

The field has been only partially explored, but the phosphorus is scattered haphazard throughout the whole deposit, so as to make careful selection necessary, and it seems certain that the greater part will run from 0.7 to 1 per cent. in phosphorus and possibly from 1 to 2 per cent. The ore is very hard and must be blasted. The sulphur is almost always below 0.10 per cent., the manganese about 0.30 per cent., but titanic acid is present in varying quantities from 0.3 to 1 per cent. In the immediate neighborhood are the Routivare deposits, of great extent, but as they contain only 50 per cent. of iron and carry 11 to 13 per cent. of titanic acid, they can hardly be looked upon as of great value.

Some of the older iron mines in Sweden offer ores of only moderate quality. The deposit at Grängesberg has been already mentioned as being from 50 to 58 per cent. in iron, from .06 to .27 per cent. in phosphorus and .03 to .25 per cent. in sulphur. These beds have only lately come into prominence, being made valuable by the development of the basic process. The far-famed Dannemora mines produce 47,000 tons per year. The phosphorus is extremely low, about .002 per cent., but the iron is 50 per cent. and the silica from 9 to 15 per cent. The Norberg mines, producing 138,000 tons, give 52 per cent. iron and from 2 to 32 per cent. of silica. Mention is sometimes made of the famous iron mountain of Taberg, but it is merely a rock carrying 31 per cent. of iron with 21 per cent. silica and 6 per cent. titanic acid. The exports of ore in 1904 amounted to about 3,000,000 tons. The Kirunavaara and Luossa-

vaara district supplied about 1,200,000 tons, the Gellivare region about 1,000,000 tons, and Grängesberg about 600,000 tons. Germany takes the greater part of this ore, but England, Belgium and other countries receive a certain quantity.

Table XXIX-B.

List of Largest Works in Sweden.

Districts.	Name of Works.	Nearest Large Town.	Steel Output in 1900; tons.
Gefleborg	Iggesund	Hudiksvall	6,000
	Forsbacka	Gefle	12,000
	Hofors	Gefle	20,000
	Sandviken	Gefle	25,000
Kopparberg	Avesta	Falun	20,000
	Langshyttan	Falun	6,000
	Domnarfvet	Falun	60,000
Vermland	Munkfors	Filipstad	6,000
	Hagfors	Filipstad	14,000
	Nykroppa	Filipstad	15,000
Örebro	Bofors*	Kristinehamn	5,000
Vestmanland	Degerfors	Kristinehamn	23,000
	Fagersta	Vesteras	19,000
	Hellefors	Filipstad	10,000
Upsala	Soderfors	Gefle	5,000
Östergotland	Motola	Motala	6,000
	Finspong	Norrköping	7,000

* Mainly steel castings, guns, armor, etc.

In Fig. XXIX-A I have combined the districts before described and have shown (1) the extreme north, a forest-covered, unsettled country, producing ore alone; (2) the extreme south, producing coal alone, and the southern central portion, making a small amount of iron; (3) the central district west of Stockholm—in which the iron industry of Sweden is centered.

Some readers may inquire concerning Norway, so it may be well to say that there is no iron made in Norway, and the amount has always been small; but a great deal of Swedish Lancashire product has been taken to that country worked into finished articles and exported under the name of "Norway iron." This term may now be a fixture in the trade, but has no place in a metallurgical treatise. In Table XXIX-B is a list of the principal steel works in Sweden, showing their location and production of steel in 1900.

CHAPTER XXX.

SPAIN.

The information concerning Spain is taken from a paper by Alsola, Jour. I. & S. I. Vol. 11, 1896, and from miscellaneous sources.

Spain claims our consideration as a source of supply for ore. It has been announced many times that the mines were exhausted, and it is a fact that the ore is growing leaner. At some mines considerable spathic ore is shipped, which was not considered of value fifteen years ago, but in spite of the immense amounts of ore produced for so many years the output has steadily increased, and the year 1899 saw by far the greatest record, the output of the mines being 9,400,000 tons, four-fifths of which was raised around Bilbao. A considerable quantity of this is smelted in the neighborhood of the mines, and there are a few steel works of considerable magnitude in the district, the fuel being drawn from coal mines in Asturias, 200 miles west of Bilbao. The local works, however, use but a small proportion of the ore output, and in 1900 over 90 per cent. was exported, the port of Bilbao sending out two-thirds of the whole. England claimed three-quarters of the shipments and Germany the greater part of the rest. Detailed figures are shown in Table XXX-A and Fig. XXX-A. The Bilbao ore proper comes from an area 15 miles in length and 2½ miles in width. Four classes are distinguished:*

(1) *Vena,* a soft purple compact and often powdery hematite.

(2) *Campanil,* a compact and crystalline red hematite, often accompanied by rhombohedra of carbonate of lime.

(3) *Rubio,* a brown hematite mixed with silicious material.

(4) *Carbonato,* a gray granular and silicious or a creamy white laminated and crystalline spathic iron ore.

Vena is the purest and was the only one used in the ancient local

*Brough, Cantor Lectures Soc. Arts, Man. and Commerce. Feb., 1900.

Catalan forges. Campanil, on account of its low phosphorus, is the most valuable, but is nearly exhausted. Rubio is the most abun-

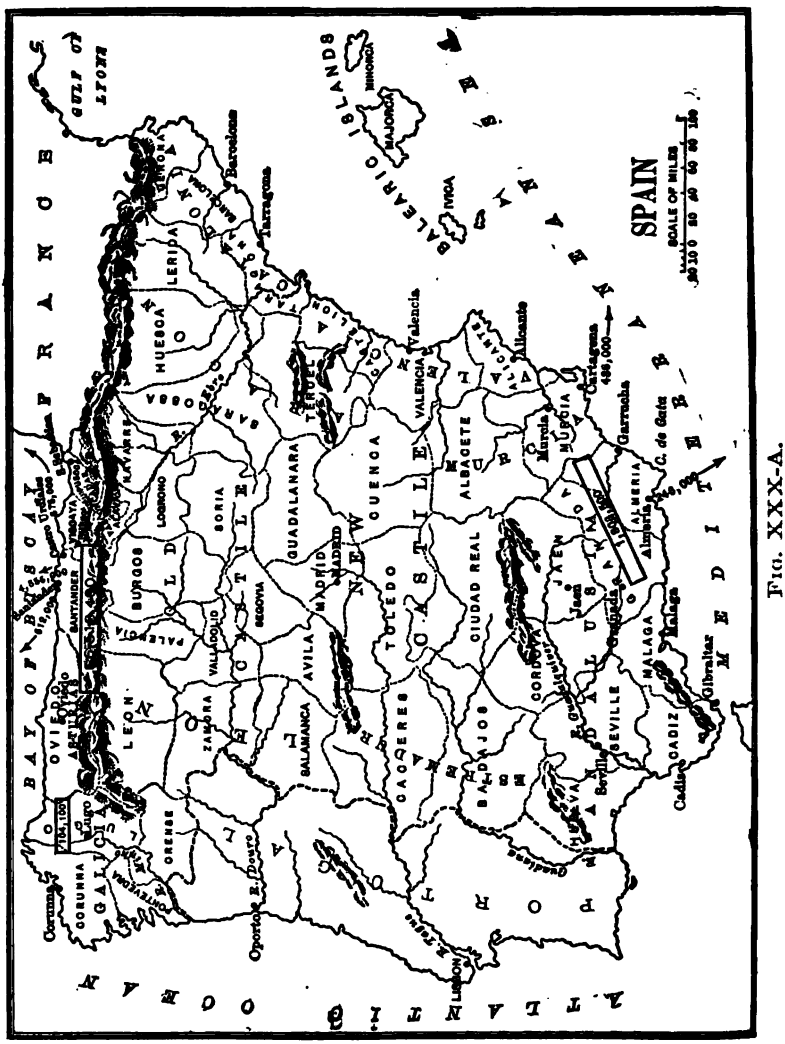


FIG. XXX-A.

dant, but is mixed with veins of iron pyrites. Carbonato is found usually below the other ores.

The district is divided into seven parts; the Sommorosto produces half the total from the beds of Triano and Matamoros. The

other districts are Galdames, Sopuerta, Ollargan, Abondo, Alonsolegui and Guenes. The Vena ore runs 56 per cent. in iron; Campanil 54 per cent., and the spathic ore from 40 to 45 per cent., giving 55 to 60 per cent. after roasting. The composition of Rubio ore, which is the great bulk of the hematite shipments, was the subject of discussion by William Whitwell, in his presidential address

TABLE XXX-A.

Spanish Ore Production and Exports.

	1899	1903
Viscaya	6,495,564	4,760,000
Santander	1,158,169	1,360,000
Murcia	668,947	735.000
Almeria and Granada	537,144	725.000
Other Provinces	537,910	898.600
Total mined	9,397,734	8,478,600
Exported	8,613,137	7,692,214
Consumed		830,665

before the Iron and Steel Institute. He compared the analyses at his own works at Thornaby, near Middlesbrough, during eleven years, and they showed a constant decrease in quality.

	1890	1900
Fe in ore as received	50.50	47.99
SiO_2 in ore as received	7.10	10.09
Moisture	9.00	9.10
Fe in dry state	55.50	52.80

The spathic ore, lately considered of much value, runs 40 to 45 per cent. in iron, giving from 55 to 60 per cent. after roasting.

In addition to the deposits of northern Spain, there are extensive deposits on the Mediterranean, the principal centers being in the provinces of Murcia, Almeria and Malaga. It is from Murcia that the Porman ore comes, the mines being near to Carthagena. This is a brown hematite rather high in silica and containing a certain amount of lead, which is not a desirable thing around an iron furnace. There are other deposits farther inland, the deposits of Morata being ten miles from the coast and those of Calaspara about 85 miles, the latter ore being a red hematite running 57 per cent. Some magnetite of poorer quality is also found. Almeria produces the Herrerias ore, containing 52 per cent. of iron and 8 per cent. of manganese, which is used for the manufacture of spiegel, and it

also furnishes the Sierra de Bedar ore from the mines of Jupiter, Porfiado and San Manuel. Some of the Bedar ore is fine and runs 60 per cent. in iron when dry, while other mines give a purple lump ore running 50 per cent. in the dry. The Sierra Alhamilla deposits at Los Banos, Alfaro and Lucainena are also in this province. They are remarkably low in phosphorus and are in the form of big hard lumps, and command an extra price for use in open-hearth furnaces.

In the province of Malaga are found the ores of Marbella, the mines lying three miles from the coast and thirty miles southwest of Malaga. This is a magnetite containing 60 per cent. of iron. There are other deposits in the vicinity of Estepona and Robledal. The province of Sevilla also produces a considerable quantity from the mines of Pedroso and Guadalcanal, but the ore must be carried over fifty miles to Sevilla and this port cannot accommodate vessels of a large size. The province of Huelva furnishes the Rio Tinta ore, which is a hard and lumpy but sulphurous deposit.

CHAPTER XXXI.

ITALY.

A certain amount of iron and steel is made in Italy, the whole country in 1899 having in operation 21 open-hearth furnaces, two Bessemer and two Robert converters. Most of the steel was made from imported pig-iron and scrap. The Terni works is the largest plant, and in 1899 it imported 90,000 tons of material, converting this into supplies for the railways and the navy. The amount of pig-iron imported is from six to eight times as much as is melted within its borders. It is necessary to mention the mines of Elba, which have been famous for centuries and which have supplied America with large quantities of low-phosphorus ores. These deposits are controlled by the Italian Government, which has leased them for short periods to contractors, but now has followed the wiser plan of giving a long lease. The terms of the contract, made in 1898, are intended to encourage the manufacture of iron and steel at home. The Government is to receive a royalty of ten cents per ton on all ore smelted in Italy, but it must receive $1.50 on all ore shipped to other countries. The company securing this lease is made up of home capital in the Island of Elba, and it is developing coal mines across the ocean in Venezuela for a supply of fuel. The lease runs twenty years, and not over 160,000 tons per year may be exported, while at least 40,000 tons must be offered to Italian furnaces.

An important point in the general problem is that in the past the ore has been taken away from Elba as return cargo in vessels carrying coal to Italy, and if such exports cease the cost of coal and coke will be higher. A still more important matter is the approaching exhaustion of the deposit. The Government has carefully surveyed the remaining supply and has limited the output so that it will last twenty or thirty years at the rate of about 250,000 tons per year. Needless to say the working of the lessening and

narrowing beds, scattered over a considerable area, will be done at a considerably increasing cost. It is safe to say, therefore, that the mines of Elba can hardly be viewed as an important factor in the international iron trade.

TABLE XXXI-A.

Exports of Ore from Elba in 1899.

	Tons.
Great Britain	102,700
Germany via Holland	53,300
United States	41,700
France	29,000
Total	226,700

CHAPTER XXXII.

CANADA.

Up to the year 1901 the iron and steel industry of Canada was of little importance, but it has now come to the front as the land of new enterprises of considerable magnitude. An extensive system of industries, of which a steel works is only a part, is developing on the Canadian side of the Sault, between Lake Superior and Lake Huron. The Bessemer plant connected with this latter enterprise consists of two six-ton converters and was started in February, 1902. It is the intention to use charcoal for fuel in the blast furnace, this charcoal being supplied from the waste in the lumbering operations conducted by the company. If this plan is found to be economical, and it is by no means out of the question, this will be the only place in the world, except in Sweden and the Urals, where a large steel plant is run on charcoal iron. During the summer of 1902 and up to the time of writing, the plant has been closed on account of financial difficulties, and the future is uncertain.

Another plant is on different lines and presents points of interest to the metallurgist. The Dominion Iron and Steel Company has built a steel works at Sydney, Cape Breton, at which point the company owns very extensive fields of rich coal. The coal varies considerably and some beds are high in sulphur, so that for the production of coke it has been found necessary to wash the coal. Table XXXII-A shows the composition of the raw material as publicly stated by the management.

The ore, which goes by the name of Wabana, comes from Great Bell Island in Concepcion Bay, Newfoundland, about 35 miles from St. Johns, and about 400 miles from the steel plant at Sydney. It is easily mined, being in well-defined thin layers and of a brittle nature, but is not of the best quality. It will give a pig-iron running about 1.5 per cent. in phosphorus, which is rather low for basic Bessemer practice and rather high for an open-hearth furnace.

TABLE XXXII-A.

Composition of Fuel and Ore at Cape Breton.

Raw Coal.	Reserve Mine.	Caledonia Mine.	Dominion Mine.
Moisture.....	1.45	1.54	1.21
Volatile Matter..	32 45	30.86	31.89
Fixed Carbon ...	60.45	62 91	61 49
Sulphur.....	1.64	1.50	1.56
Ash.....	5.65	4.69	5.41
Washed Coal—			
Moisture.....	1.01	1.06	0.84
Volatile Mattter.	32.99	33.92	37.86
Fixed Carbon....	62.21	61.69	62.60
Sulphur.....	1.11	1.07	1 17
Ash.....	3.79	3.31	4.50
Retort Coke—			
Sulphur.....	0.91	0.78	1.01
Ash.....	6.07	5.38	6.24

Bell Island Ore.	Best.	Worst.
Moisture.....	1.50	2.50
Fe.....	54.43	51.84
SiO_2.....	9 34	13.00
P.....	0.744	0 835
S.....	0.05	0.03

There are four blast furnaces 85 by 20 feet and ten 50-ton open-hearth furnaces of the Campbell type. The first steel was made on December 31, 1901. Sydney is on a good harbor, but this is closed by ice a part of the year, during which time traffic can be carried on by way of Louisburg, forty miles by railroad on the south coast. The ore deposit at Bell Island is also on good water, but is likewise ice-bound for three or four months in the year.

In this same district are the two works of the Nova Scotia Steel Co., with eight open-hearth furnaces.

One of the arguments advanced in favor of new works in Canada is the bounty offered by the Government on pig-iron and steel manufactured within the Dominion. During the year 1905 the bounty is $1.05 on every ton of pig-iron made from native ore, and an additional $1.05 for every ton of steel, making a total of $2.10 for each ton of steel from native ore. This falls to $1.20 during 1906, and then ceases altogether.

CHAPTER XXXIII.

STATISTICS OF THE IRON INDUSTRY.

In Tables XXXIII-D to L, inclusive, is given the production of coal, iron ore, iron and steel in the leading nations. In the case of some countries certain information can hardly be obtained at all, as, for instance, in regard to the production of wrought-iron or of lignite in the United States. In other cases there is much difference in the way the figures are usually given. In the United States the production of steel is the ingot weight. We do have a figure of finished rolled material, but this includes the wrought-iron. In England the ingot is also used, but in some other countries the data are given for the finished bar, while in Belgium the records show the weight of the blooms or billets in the intermediate stage.

Judging from my own ignorance in the matter, it is doubtful if most people appreciate the difficulty of obtaining accurate statistics of production. This will be illustrated by Table XXXIII-A, which gives figures on the output of steel in Germany. The data from Wedding were collected exclusively for this book, and as they disagreed with other records an investigation was made for me by Consul-General Mason in Berlin. The different figures were then sent to Mr. Schrödter and I asked for an explanation of what is meant by finished steel, and whether the same metal could appear twice in Mason's tabulation. Mr. Schrödter states that not until the year 1900 were any records kept of the output of ingots, but does not cast any light on the question of duplication. He does state, however, that the amount of finished material in 1900 was 6,361,650 tons, which is given by Mason as the total output. He also states that the total production of ingots and castings was 6,645,869. This is the same thing as saying that the weight of finished material was 95.72 per cent. of the weight of the ingots, a difference of only 4.28 per cent. to account for all scrap and oxidation, and I can hardly believe that the figures are correct.

TABLE XXXIII-A.

Discordant Data on Steel Output in Germany.

Source of Information.	1898	1899	1900	1901
Swank; Am. I. & S. Ass., 1901	.....	6,328,666	6 385 259	.....
Mineral Industry, 1901	5 734 307	6 290,434	6 645,869	.....
Rentzsch	5 065,896	5,667,050	6.645.869	.....
Gemeinfass, Darstell, 1901	4,352,831	4,791,022	4,799,000	.....
Wedding*	....	4,967,770	.....	.....
Mason;* ingots	441 601	467 721	352 935	
Blooms, billets, etc.	966 572	1 040,670	1,183,128	.....
Finished steel	4,352,831	4,820,275	4,825,587	.....
Total	5,781,004	6,328,666	6,361,650	.....
Schrödter;* steel castings	.....	.....	.....	107.210
Bess. and O. H. ingots	....	....	.....	6,287,013
Total	.....	.....	6,645,369	6,394,223

* Private Communication.

Much confusion is caused by differences in classification. The term "iron and steel productions" may include pig-iron and may not. The term "bar-iron" may mean wrought-iron, or may include steel, as soft steel is called ingot-iron on the Continent. Sometimes steam engines are in "iron and steel exports," and sometimes under machinery. It is difficult to find the truth without a detailed analysis of the original records, which is not often practicable.

The iron producers may be divided into three classes according to the quantity of pig-iron and steel they produce. First, and almost in a class by itself, is the United States; next come Germany and Great Britain. These three nations produce eighty per cent. of all the coal, pig-iron and steel made in the world, and nearly seventy per cent. of the iron ore.

In the next class are France, Russia, Austria and Belgium. These four nations produce eighteen per cent. of all the pig-iron and steel made in the world, and fifteen per cent. of all the coal and iron ore.

The third class includes Sweden and Spain, which are important as sources of the iron supply for the greater nations, but which have no coal for smelting. In the same list, but of less importance, are Greece, Algeria, Cuba and Italy, which are widely known for their ore mines, but produce little or no iron.

Another comparison is according to the pig-iron produced per inhabitant, as shown in Table XXXIII-B.

TABLE XXXIII-B.

Production of Pig-Iron per Capita in 1899; pounds.

Great Britain	505
United States	405
Germany	330
Belgium	322
Sweden	244
France	145
Austria-Hungary	67
Russia	46
Italy	1

The United States is self-contained, possessing within its borders all the material necessary for the iron industry. Some ore is imported for plants near the seaboard, and small lots of foreign pig-iron find their way into the country, but the proportion of imports is small for either fuel, ore, iron or steel. This arises from the geographical isolation of America and the prohibitory distances from other sources of supply. To understand the different conditions in Europe it is only necessary to consider that the boundary of France touches the coal of Belgium, and the boundary of Belgium touches the ore of Luxemburg. The close geographical relations of the countries in northwestern Europe naturally give rise to inter-traffic in raw materials, when unhampered by foolish tariff restrictions on such articles. The iron industry of Belgium is founded on imported ore, while France, Germany and England bring from one-fifth to one-third of their ore supply from beyond the boundary. Belgium imports almost all her ore, and Great Britain and France import about one-third of all that is used. On the other hand, Germany exports almost as much as she imports, while Sweden sends most of her ore abroad.

Belgium and Germany are the only nations that import any considerable portion of their pig-iron, while Great Britain is the only one that exports any important amount. In 1899 and 1900 the latter nation exported 15 per cent. of her pig-iron. In these two years the United States exported only two per cent. and Germany the same, while in 1901 the United States sent abroad only one-half of one per cent. of her pig-iron.

In wrought-iron and steel, Great Britain, Russia and Belgium

import quite a considerable proportion of their total production, while the United States imports a very small percentage. Singularly enough, the nations that import the greatest proportion also export the greatest, for England exports one-third of her finished iron and steel, and Belgium nearly one-half of her output. The United States up to the present time has shipped away only a small proportion of her output, but in 1900 it reached 12 per cent. of the total.

This comparison gives some idea of the character of the business of these nations, but it does not convey any definite information about the extent to which these nations influence the commerce of the world. Thus, although the United States sent abroad only a small proportion of her products, the actual tonnage so exported in 1900 was nearly three times the over-sea shipments of Belgium, although the latter nation sent nearly half of her products to other countries. The overshadowing factors in over-sea commerce are Great Britain, Germany and the United States. Other nations play a small part in the general international iron trade.

There are some people who may look for a table giving the rate of wages in each country, and possibly it would please my political friends to have figures tabulated to prove some tariff theories. It would be easy to give statistics on either side. From personal knowledge I could quote the earnings of boiler-makers in free-trade England at over $7 per day and the wages of skilled rolling-mill men at $1.50 in protectionist Germany and Austria. It is well known to manufacturers and employers of labor that the information collected by our Government is hardly worth the trouble of printing, but statisticians are constantly quoting the records for want of better information. The weak points are recognized by the Department itself, but there are difficulties in the way of obtaining data. Thus it is of little use to record that the wages of bricklayers are $5 per day in a certain city and only $2.50 in a certain town, for it is quite probable that in the city the work is intermittent, made up of short jobs interrupted by weather, so that from inclement days and intervals between jobs, the annual earnings will be no more than in the town where perhaps a steel works offers steady work under shelter in rough weather throughout the whole year, and where the rent and cost of living is less than in the greater community. It is also of little value to give the aver-

age amount of money drawn by an employee, for it is necessary to know whether every man worked full time.

It is not in the province of this book to discuss the future, but it may be well to call attention to the serious inroads now being made upon the supply of iron ore. In 1865 the world mined about 18,000,000 tons of ore, and in 1903 over 100,000,000 tons. If this rate of increase continues during the coming years the consump-

TABLE XXXIII-C.

Approximate Annual Output in the Pig-Iron-Producing Districts.

District.	Tons.
Pittsburgh; parts of Pennsylvania, Ohio, and W. Va., U. S. A.	8,350,000
The Ruhr; western Westphalia, Germany	4,010,000
Lothringen and Luxemburg, Germany	3,210,000
Northeast coast of England; (Cleveland)	3,000,000
Eastern France; the Minette District	1,800,000
Illinois, U. S. A.	1,650,000
West coast of England; Lancashire and Cumberland	1,500,000
Alabama, U. S. A.	1,450,000
Southern Russia	1,350,000
Belgium	1,300,000
Scotland	1,250,000
South Wales	880,000
Cleveland, Ohio, U. S. A.	850,000
Silesia, Germany	750,000
The Saar, Germany	740,000
Steelton; Dauphin and Lebanon Counties, Pennsylvania	700,000
The Siegen, Germany	700,000
Eastern Central England	640,000
The Urals, Russia	640,000
Johnstown, Pa., U. S. A.	610,000
New York and New Jersey, U. S. A.	590,000
Staffordshire, England	570,000
Central England	560,000
Virginia, U. S. A.	500,000
Lehigh Valley, Pa., U. S. A.	500,000
Central Sweden	500,000
Southeast Pennsylvania, U. S. A.	450,000
Hungary	430,000
Tennessee, U. S. A.	400,000
Moravia and Silesia, Austria	320,000
Hanging Rock, Ohio, U. S. A.	300,000
Sparrow's Point, Md., U. S. A.	300,000
Northern France	300,000
Spain	300,000
Styria, Austria	300,000
Poland, Russia	300,000
Sheffield, England	280,000
Canada	270,000
Bohemia, Austria	260,000
Central France	250,000
All other districts and countries	3,310,000
Total for the world	46,370,000

tion in 1935 will be so rapid that in a period of five years, say from 1935 to 1939 inclusive, as much ore will be smelted as was used from 1880 to 1900.

We are today eating up the hoardings of untold geologic ages at a rate which will exhaust the known rich deposits during the present century. When these are gone it may be that others will be discovered, and it may be that the eastern part of the United

TABLE XXXIII-D.

Approximate Annual Output in the Steel-Producing Districts.

District.	Tons.
Pittsburgh; parts of Pennsylvania, Ohio, and W. Va., U. S. A.	7,400,000
The Ruhr, western Westphalia, including Aachen, Germany	4,660,000
Illinois, U. S. A.	1,750,000
Lothringen and Luxemburg, Germany	1,410,000
Northeast coast of England; (Cleveland)	1,300,000
The Saar, Germany	1,040,000
South Wales	1,000,000
Belgium	1,000,000
South Russia	980,000
Scotland	950,000
Cleveland, Ohio, U. S. A.	870,000
Johnstown, Pa., U. S. A.	800,000
West coast of England; Lancashire and Cumberland	800,000
Eastern France; the Minette District	650,000
Silesia, Germany	590,000
South Yorkshire, England	560,000
New York and New Jersey, U. S. A.	550,000
Southeast Pennsylvania, U. S. A.	500,000
Steelton, Pa., U. S. A.	440,000
Northern France	380,000
Staffordshire, England	380,000
Hungary	350,000
Sparrow's Point, Md., U. S. A.	350,000
Central France	310,000
The Urals, Russia	290,000
Poland, Russia	280,000
Central Sweden	280,000
Styria, Austria	250,000
Colorado, U. S. A.	240,000
Ilsede, Germany	240,000
Moravia and Silesia, Austria	230,000
Bohemia, Austria	210,000
New England, U. S. A.	200,000
Spain	200,000
Italy	190,000
Moscow, Russia	190,000
Canada	180,000
North Russia	180,000
The Siegen, Germany	150,000
Saxony, Germany	140,000
All other districts and countries	3,380,000
Total for the world	35,850,000

States will depend upon the concentration of the lean beds of New York, New Jersey, Pennsylvania and Alabama, while Europe will work the mammoth beds of Luxemburg and Lothringen. It is to be expected that the Rocky Mountains will furnish new fields, while Africa and the unknown corners of the earth may be relied on to prevent a catastrophe.

TABLE XXXIII-E.

Production of Coal, Ore, Pig-Iron and Steel in 1903.

NOTE: One unit = 1,000 gross tons.

	Coal.		Ore.		Pig Iron.		Steel.	
	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.	Tons.	Per cent. of total.
United States	319,068	36.5	35,019	34.4	18,009	38.8	14,535	40.6
Great Britain	230,334	26.4	13,716	13.5	8,985	19.3	5,134	14.3
Germany and Luxemburg	162,457	18.6	21,231	20.9	10,096	21.8	8,802	24.5
France	34,906	4.0	6,220	6.1	2,841	6.1	1,885	5.3
Belgium	23,797	2.7	184	0.2	1,217	2.6	969	2.7
Austria-Hungary	40,629	4.7	3,269	3.2	1,428	3.1	1,196*	3.3
Russia and Finland	17,500	2.0	5,648*	5.6	2,454	5.3	2,375	6.6
Sweden	320	.....	3,678	3.6	507	1.1	319	0.9
Spain	2,587	0.3	8,304	8.2	308	0.7	200	0.6
Italy	347	.....	375	0.4	75	0.2	187	0.5
Canada	6,825	0.8	236	0.2	265	0.6	182	0.5
Cuba	.....	.....	625	0.6	.....	.....	.....	.....
Transvaal	2,258	0.3	.....	.....	.....	.....	.....	.....
India	7,438	0.9	85*	0.1	.....	.....	.....	.....
New South Wales	6,355	0.7	14*	.....	.....	.....	.....	.....
Japan	9,702*	1.1	70†	0.1	.....	.....	.....	.....
New Zealand	1,490	0.2	.....	.....	.....	.....	.....	.....
Greece	11	.....	360	0.4	.....	.....	.....	.....
Algeria	.....	.....	589	0.6	.....	.....	.....	.....
Other countries	7,581	0.8	2,162	1.9	248	0.4	65	0.2
Total	873,535	100.0	101,785	100.0	46,368	100.0	35,846	100.0

* = 1902. † = 1901.

TABLE XXXIII-F.

Production of Coal (all kinds); 1 unit = 1000 gross or metric tons.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Russia.	Austria-Hungary.	Belgium.
1880....	63,823	146,969	59,118	19,362	3,238	14,800	16,867
1885...	99,250	159,351	73,676	19,511	4,208	20,435	17,428
1890...	140,867	181,614	89,057	26,083	6,017	27,504	20,366
1895...	172,426	189,661	103,958	28,080	9,079	32,655	20,415
1896...	171,416	195,361	112,471	29,190	9,229	33,676	21,252
1897...	178,769	202,119	120,474	30,796	11,207	35,939	21,492
1898...	196,407	202,042	127,959	32,356	12,242	37,786	22,088
1899...	226,555	220,085	135,844	32,863	13,558	38,738	22,072
1900...	240,789	225,181	149,788	33,270	14,913	38,064	23,463
1901...	261,874	219,047	152,629	32,325	16,270	41,208	22,213
1902...	269,277	230,729	150,600	29,997	15,503	39,387	22,877
1903...	319,068	224,009	162,620	35,008	16,200	39,600	23,871
1904...	314,123	232,428	169,451	34,168	19,318	41,014	22,761
1905...	350,821	236,129	178,797	.....	.....	.....	21,844

TABLE XXXIII-G.

Production of Iron Ore; 1 unit = 1000 gross or metric tons.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France	Russia.	Austria-Hungary.	Belgium.	Sweden.	Spain.
1880...	7,120	18,026	7,239	2,874	1,024	1,143	253	775	3,565
1885...	7,600	15,418	9,158	2,318	1,094	1,582	187	873	3,933
1890...	16,036	13,781	11,410	3,472	1,796	2,154	172	941	6,546
1891...	14,591	12,778	10,658	3,579	1,999	2,107	202	987	4,882
1892...	16,297	11,313	11,539	3,707	2,044	1,914	210	1,294	5,436
1893...	11,588	11,203	11,458	3,517	2,095	2,086	239	1,484	5,498
1894...	11,880	12,367	12,392	3,772	2,488	2,115	311	1,927	5,397
1895...	15,958	12,615	12,350	3,680	2,927	2,340	313	1,905	5,514
1896...	16,005	13,701	14,162	4,062	3,205	2,719	307	2,039	6,763
1897...	17,518	13,788	15,466	4,582	4,112	3,065	241	2,087	7,420
1898...	19,434	14,177	15,893	4,731	4,871	3,401	217	2,303	7,197
1899...	24,683	14,461	17,990	4,986	5,880	3,853	201	2,435	9,398
1900...	27,553	14,023	18,964	5,448	5,989	3,462	248	2,610	8,480
1901...	28,887	12,275	16,570	4,791	5,663	3,643	219	2,795	7,907
1902...	35,554	13,426	17,964	5,004	5,648	3,329	166	2,897	7,905
1903...	35,019	13,716	21,231	6,220	4,219	3,269	184	3,678	8,479
1904...	27,600	13,774	22,047	7,023	5,272	3,381	207	4,085	7,905
1905...	42,526	14,591	23,444	.....	.....	.....	.....	4,395	9,355

TABLE XXXIII-H.

Production of Pig-Iron; 1 unit = 1000 gross or metric tons.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Russia.	Austria-Hungary.	Belgium.	Sweden.
1880....	3,835	7,749	2,729	1,725	471	464	608	6
1885....	4,045	7,415	3,687	1,631	552	715	718	6
1890....	9,203	7,904	4,658	1,962	950	965	788	6
1891....	8,280	7,406	4,641	1,897	1,028	922	684	6
1892....	9,157	6,709	4,937	2,057	1,038	941	753	6
1893....	7,125	6,977	4,986	2,003	1,181	982	745	6
1894....	6,657	7,427	5,380	2,070	1,333	1,020	819	6
1895....	9,446	7,703	5,465	2,004	1,454	1,108	899	6
1896....	8,623	8,660	6,373	2,340	1,867	1,218	959	6
1897....	9,653	8,796	6,881	2,484	1,869	1,330	1,035	6
1898....	11,774	8,610	7,313	2,534	2,222	1,427	983	6
1899....	13,621	9,421	8,143	2,567	2,726	1,467	1,038	6
1900....	13,789	8,960	8,521	2,714	2,667	1,458	1,019	6
1901....	15,878	7,929	7,880	2,389	2,808	1,300	765	6
1902....	17,821	8,680	8,530	2,427	2,596	1,335	1,103	6
1903....	18,009	8,935	10,086	2,841	2,210	1,355	1,217	6
1904....	16,497	8,563	10,104	3,000	2,978	1,413	1,307	6
1905....	22,992	9,593	10,988	3,077	.....	.....	1,310	6

TABLE XXXIII-I.

Production of Steel; 1 unit = 1000 gross or metric tons.

Year.	United States.	Great Britain.	Germany and Luxemburg.	France.	Russia.	Austria-Hungary.	Belgium.	Sweden.
1880....	1,247	1,375	661	389	296	134	132	89
1885....	1,712	1,968	1,208	554	198	279	155	81
1890....	4,277	3,679	2,162	562	378	500	221	169
1891....	3,904	3,257	2,563	699	433	486	244	173
1892....	4,928	3,020	2,756	682	515	511	260	159
1893....	4,020	3,050	3,163	664	631	569	273	166
1894....	4,412	3,211	3,642	693	726	660	406	168
1895....	6,115	3,390	3,963	900	879	745	455	232
1896....	5,282	4,233	4,821	1,160	1,023	878	599	251
1897....	7,157	4,586	5,137	1,282	1,205	929	617	268
1898....	8,933	4,606	5,781	1,442	1,596	1,055	653	264
1899....	10,640	4,955	6,329	1,499	1,939	1,117	731	272
1900....	10,188	5,001	6,646	1,565	1,463	1,134	655	300
1901....	13,474	4,897	6,394	1,425	1,815	1,143	527	270
1902....	14,947	5,009	7,781	1,635	1,730	1,144	777	284
1903....	14,535	5,134	8,802	1,863	1,525	1,146	962	310
1904	13,860	5,127	8,990	2,107	.....	.....	1,083	334
1905....	20,024	5,989	10,067	2,137	.....	.....	1,165	361

APPENDIX.

Value of Certain Factors Used in Iron Metallurgy.

ATOMIC WEIGHTS.

Fe,	56	Si,	28	C,	12
Mn,	55	Ca,	40	O,	16
S,	32	Mg,	24	N,	14
P,	31	Al,	27	Ti,	48
Ni	59	Cr	52	W	184

CONTENT OF METALLIC IRON IN PURE COMPOUNDS OF IRON.

$FeCO_3$	$\frac{7}{12}$ or 48.28	per cent.
FeO	$\frac{7}{9}$ or 77.78	"
Fe_2O_3	$\frac{7}{10}$ or 70.00	"
Fe_3O_4	$\frac{21}{29}$ or 72.41	"

REACTIONS IN OPEN-HEARTH FURNACES.

100	pounds	$CaCO_3$	produce	56	pounds	CaO.
100	"	$MgCO_3$	"	48	"	MgO.
100	"	Si	"	214	"	SiO_2.
100	"	Mn	"	129	"	MnO.
100	"	Fe	"	128	"	FeO.
100	"	P	"	229	"	P_2O_5.
100	"	C	"	233	"	CO.
100	"	C	"	367	"	CO_2.

Properties of Air.

Composition by volume { 0=20.9 per cent. N=79.1 per cent.
0 : N=1 : 3¾=4 : 15.

Composition by weight { 0=23.2 per cent. N=76.8 per cent.
0 : N=3 : 10

Weight of 1 cubic metre=1.293 kilogrammes.

Weight of 1 cubic foot=0.0807 pounds.

Coefficient of expansion { Constant volume=0.003665
Constant pressure=0.003670

Standard Factors in English and Metric Systems.

Abbreviations: Cubic metre=cu. m.; cubic foot=cu. ft.; kilogramme=kg.; pounds=lbs.; square millimetre=sq. mm.; British thermal unit=B. t. u.; calorie=cal.

1 metre=39.37 inches.
1 cu. m.=35.316 cu. ft.
1 kg.=2.2046 lbs.
1 kg. per sq. mm.=1422.32 lbs. per sq. inch.
1 kg. per cu. m.=0.0624 lbs. per cu. ft.
1 gross ton=2240 lbs.
1 metric ton=2205 lbs.
1 calorie raises 1 kg. of water 1° Cent.
1 B. t. u. raises 1 pound of water 1° Fahr.
1 calorie=3.968 B. t. u.
1 cal. per cu. m.=0.112 B. t. u. per cu. ft.
1 cal. per kg.=1.8 B. t. u. per pound.
1 B. t. u. per cu. ft.=8.9 cals. per cu. metre.
1 kg. per cu. metre=0.0624 lbs. per cu. ft.
1 Boiler horse-power=33305 B. t. u. per hour.
1 Boiler horse-power=8390 calories per hour.
1 Indicated horse-power=61090 B. t. u. or 15394 calories when used continuously for 24 hours.

Gravimetric and Calorific Values.

	Weight per Volume.		Products of combustion.	Calorific Value.				Specific Heat. Cals. per cu. m. or B. t. u. per cu. ft.
	Kg. per cu. m.	Lbs. per cu. ft.		Cals. per kg.	Cals. per cu. m.	B. t. u. per lb.	B. t. u. per cu. ft.	
Air	1.29	0.080	.....	.....	.....	.....	.....	0.307
N	1.26	0.079	.....	.....	.....	.....	.....	0.307
O	1.43	0.089	.....	.....	.....	.....	.....	0.312
CO_2	1.97	0.123	.....	.....	.....	.....	.....	0.426
CO	1.25	0.078	CO_2	2438	3072	4390	345	0.310
H	0.09	0.0056	H_2O	29040	2614	54000	294	0.305
CH_4	0.72	0.045	CO_2 and H_2O	11970	8620	21546	967	0.424
C_2H_4	1.25	0.078	CO_2 and H_2O	10800	12480	18540	1454	0.463
C	.....	.....	CO	2450	.....	4410	.....	.....
C	.....	.....	CO_2	8133	.....	14640	.....	.....
Si	.....	.....	SiO_2	6414	.....	11545	.....	.....
P	.....	.....	P_2O_5	5740	.....	10330	.....	.....
Fe	.....	.....	FeO	1173	.....	2110	.....	.....
Fe	.....	.....	Fe_2O_3	1746	.....	3140	.....	.....
Mn	.....	.....	MnO	1635	.....	2940	.....	.....

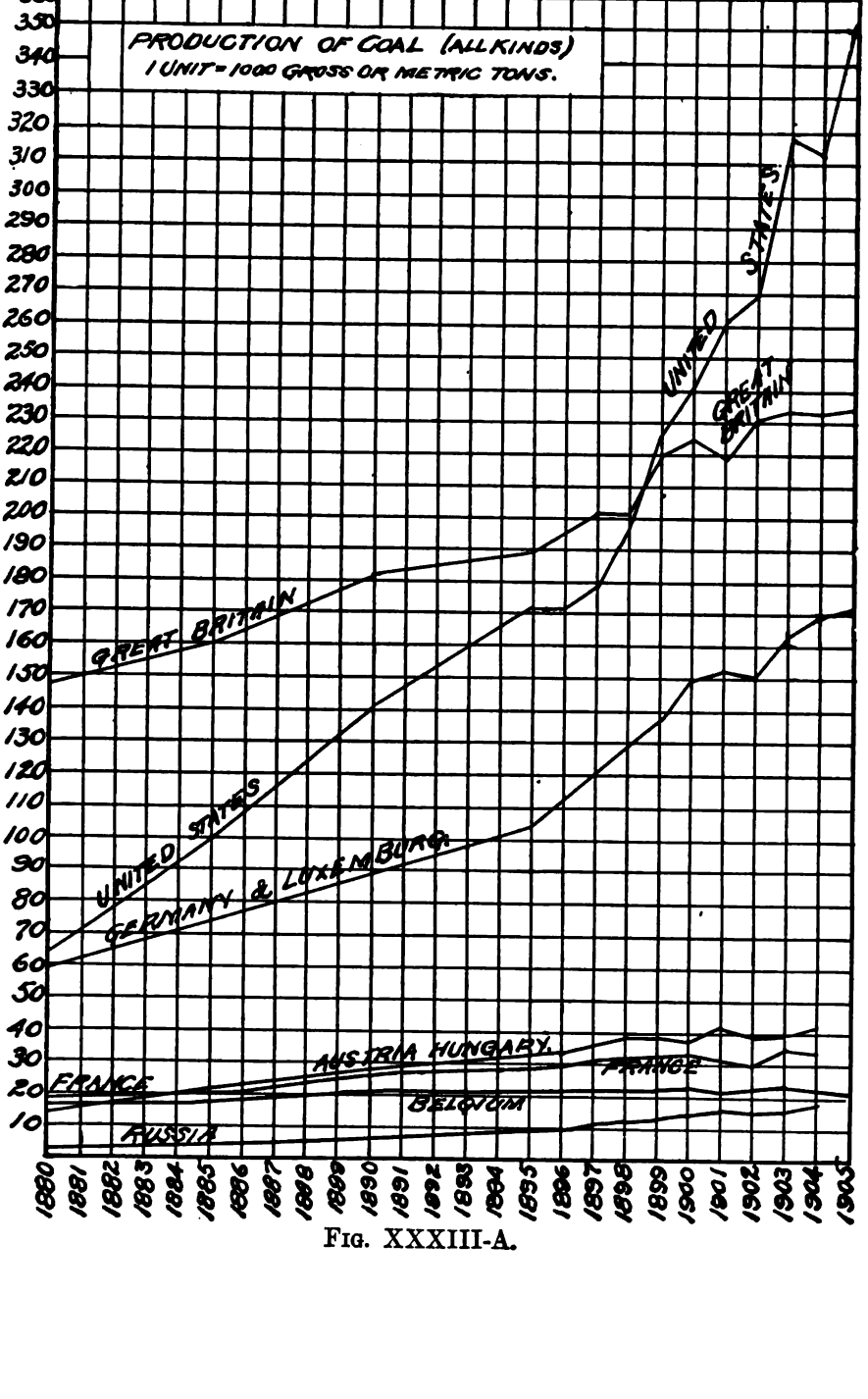
FORMULÆ FOR SPECIFIC HEAT OF GASES BETWEEN 0°C and t°C.

CO_2	$= 0.374 + 0.00027\,t$
CO, O, H, N and O	$= 0.303 + 0.000027\,t$
H_2O	$= 0.342 + 0.00015\,t$
CH_4	$= 0.418 + 0.00024\,t$
C_2H_4	$= 0.424 + 0.00052\,t$

Mariotte's Law.—The volume of a gas is directly proportional to the absolute temperature and inversely proportional to the pressure upon it.

Note: Absolute zero = − 273·5°C.

Law of Dulong and Petit.—The product of the atomic weight of an elementary substance by its specific heat is always a constant quantity.


PRODUCTION OF COAL (ALL KINDS)
1 UNIT = 1000 GROSS OR METRIC TONS.
UNITED STATES
GREAT BRITAIN
GREAT BRITAIN
UNITED STATES
GERMANY & LUXEMBURG
AUSTRIA HUNGARY.
FRANCE
FRANCE
BELGIUM
RUSSIA
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
1880
1881
1882
1883
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1890
1891
1892
1893
1894
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1899
1900
1901
1902
1903
1904
1905

FIG. XXXIII-A.

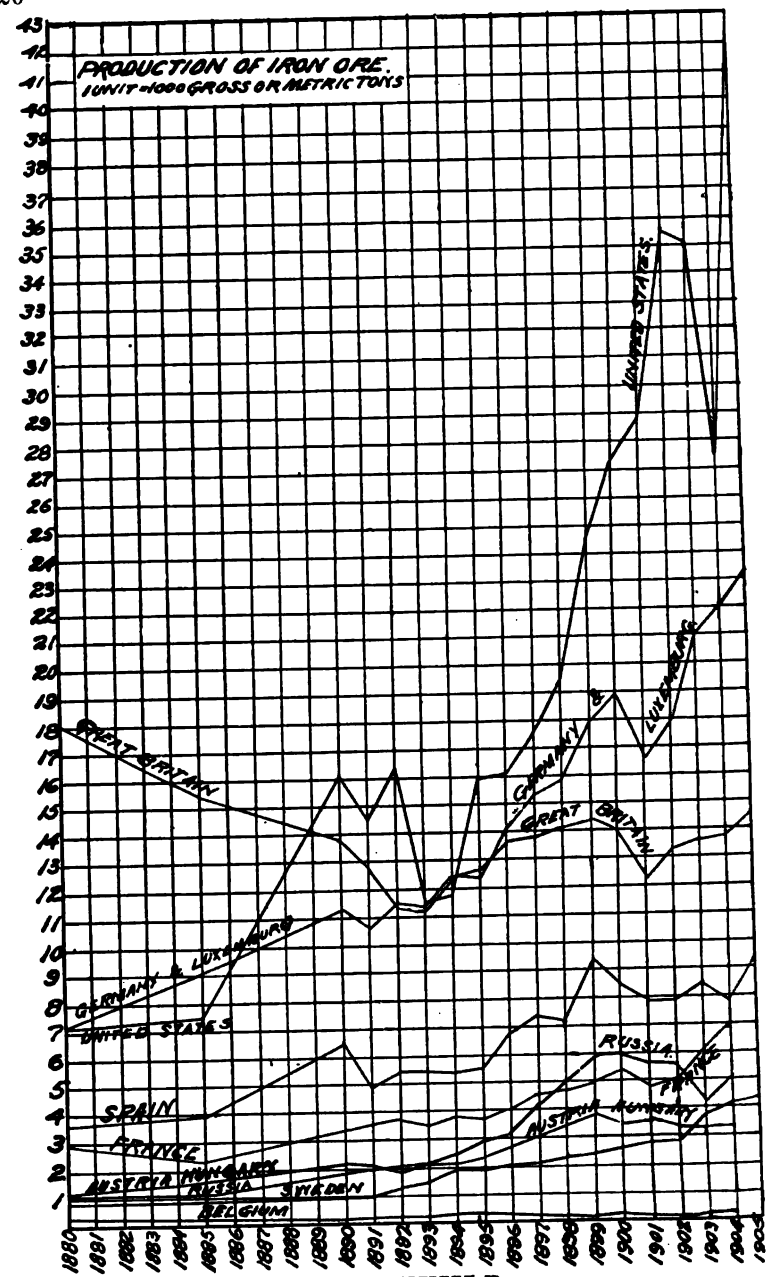
PRODUCTION OF IRON ORE.
1 UNIT = 1000 GROSS OR METRIC TONS
UNITED STATES
LUXEMBURG
GERMANY &
GREAT BRITAIN
GERMANY & LUXEMBURG
UNITED STATES
RUSSIA
FRANCE
SPAIN
AUSTRIA HUNGARY
FRANCE
SPAIN
AUSTRIA HUNGARY
RUSSIA
SWEDEN
BELGIUM

FIG. XXXIII-B.

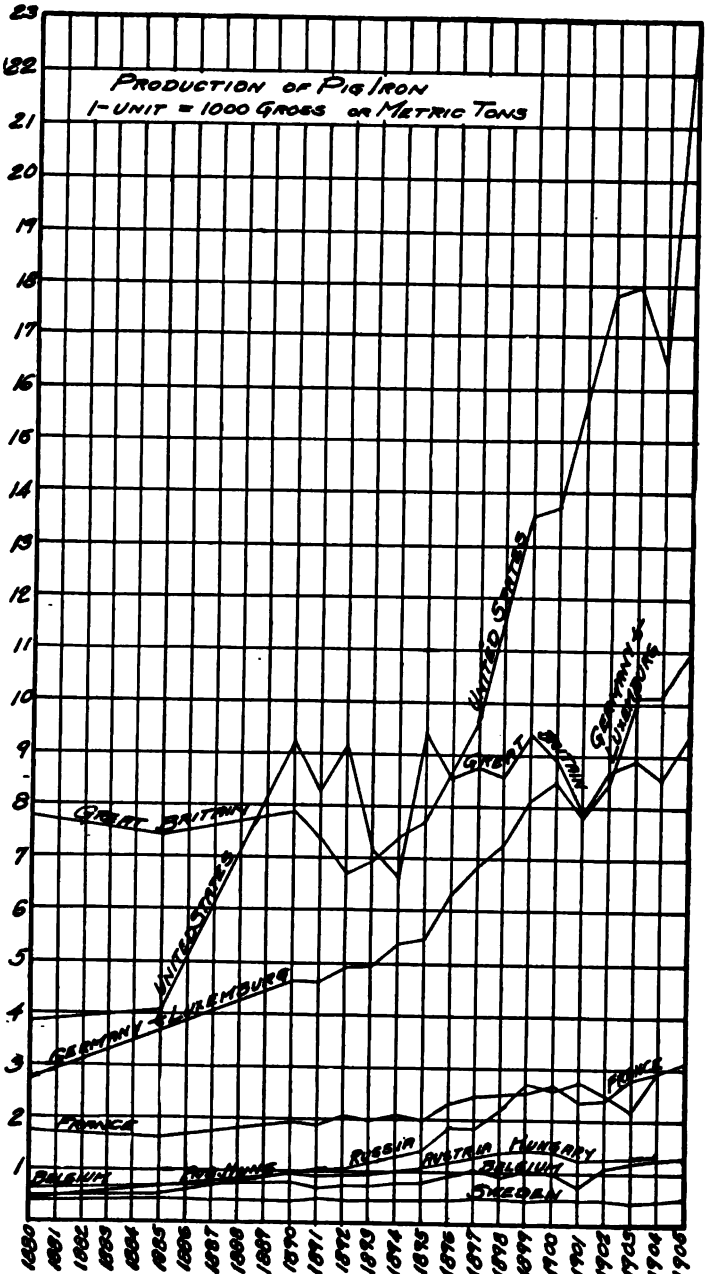
PRODUCTION OF PIG IRON
1-UNIT = 1000 GROSS OR METRIC TONS
UNITED STATES
GERMANY & LUXEMBURG
GREAT BRITAIN
GERMANY & LUXEMBURG
UNITED STATES
GREAT BRITAIN
FRANCE
RUSSIA
AUSTRIA HUNGARY
BELGIUM
SWEDEN
FRANCE
BELGIUM
1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905

FIG. XXXIII-C.

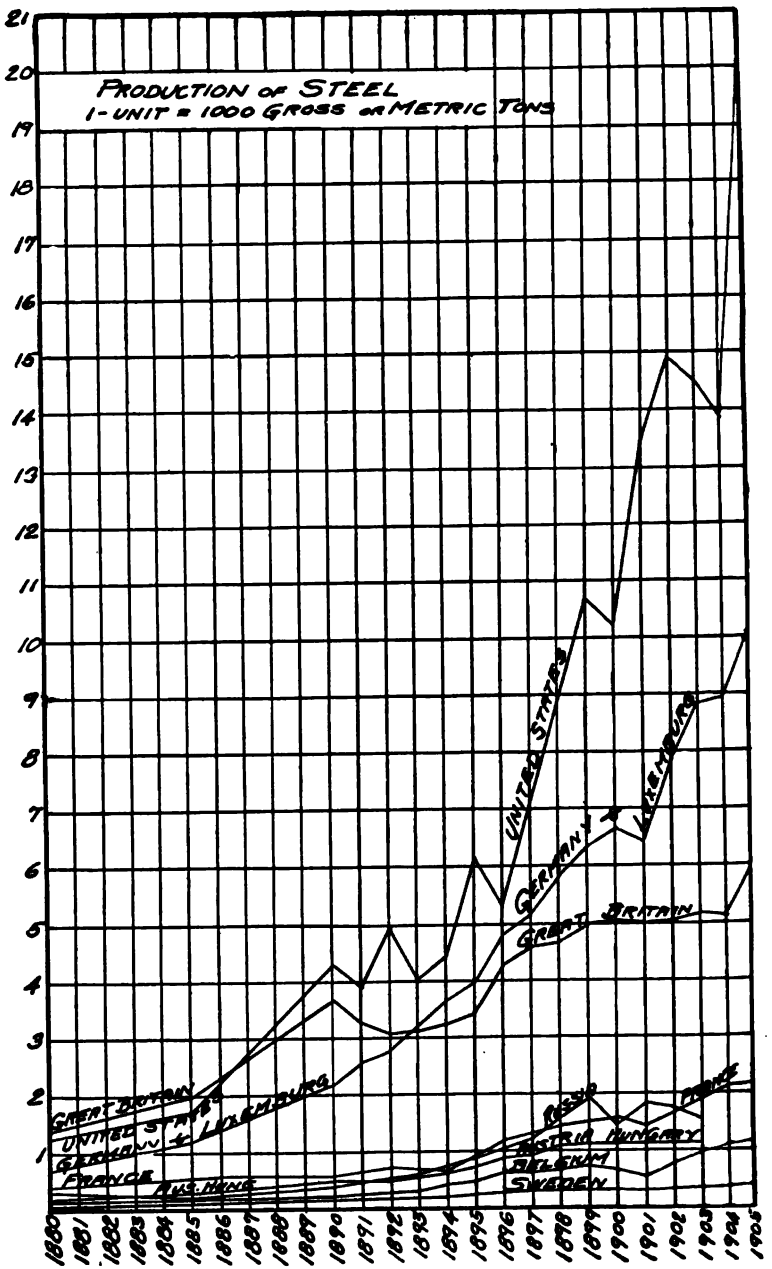
PRODUCTION OF STEEL
1-UNIT = 1000 GROSS OR METRIC TONS
UNITED STATES
GERMANY & LUXEMBURG
GREAT BRITAIN
GREAT BRITAIN
UNITED STATES
GERMANY & LUXEMBURG
FRANCE
AUS. HUNG.
RUSSIA
AUSTRIA HUNGARY
BELGIUM
SWEDEN
CANADA

FIG. XXXIII-D.

INDEX.

PAGE

Aachen iron industry 548
Absolute zero 618
Acid open hearth process 12, 179
Acid vs. Basic Steel 14, 23, 25, 28
Air, composition of 159
Air, properties of 617
Air needed in combustion 160
Akerman, on Swedish Bessemer work ..... 104 *et seq.*
Alabama, iron industry 41, 477
Algeria, statistics 615
Allegheny County 468
Allotropic forms, microscopic 296
theory 311
Alpha iron 311
Alumina in blast furnace slag 51
Aluminum, influence on physical properties 361
in castings 413
Alzola, on Spanish ores 601
American practice 470
American Society for Testing Materials 25
American Steel Manufacturers' Association 24
Angles, physical properties ..... 264 *et seq.*
Annealing ..... 274 *et seq.*, 320
Anthracite, combustion of 159, 160
in blast furnace 43, 447
in producers 166
in Russia 567
mining districts in United States 450
Appleby, on tests of rounds 325
Arnold, on sub-carbide theory 312
Arsenic, effect on physical properties 363
Ash from producer 168
Ash in coal 163, 164, 178
Atomic weights 617
Austenite ..... 296 *et seq.*
Australia, statistics 615

PAGE
Austria-Hungary, iron industry 576
statistics ..... 615 *et seq.*
Ayrshire, see Scotland.

Bahnis-Roozeboom, on phase doctrine 311
Ball, on effect of copper 360
Barba, on tests of steel ..... 326 *et seq.*
Barrow-in-Furness 517
Basic vs. acid steel 14, 23, 25, 28
Basic linings, functions of 190
Basic open hearth process 15, 190
Bauxite for basic hearths 190
Bessemer, acid process 7, 100
basic process 8, 113
basic at Troy 494
basic steel, quality 14
calorific history, acid ..... 108 *et seq.*
calorific history, basic 119
for steel castings 26, 410
gases from 106
increments in cost 232
in Sweden 104, 108
iron burned, acid 107
iron burned, basic 120
lime used, basic 115
pig iron 5
slag, acid 106
slag, basic 116
steel 6
vs. open hearth 14
Bavaria, iron industry 551
Belgium, coal fields 554
iron industry 587
labor question 591
statistics ..... 615 *et seq.*
Bell, on blast furnace reactions ..... 50, 60, 61, 67 *et seq.*
Bertrand, on Austria-Hungary 576
Bertrand-Thiel process ..... 216 *et seq.*, 225, 227, 579
Beta iron 311
Bethlehem works 493
Bilbao ore 41
Bituminous coal 450
in gas producer 161
Black band 41, 511, 521
Blast, for blast furnaces 45
heating of 46, 77

PAGE
Blast furnace....3, 4, 5, 37 *et seq.*
boilers....69, 77, 79
chemical reactions....53 *et seq.*
gas in gas engines.... 80
height of.... 40
Blauvelt, on coke ovens.... 175
Blister steel.... 94
Blow-holes in steel castings.... 412
Bohemia, iron industry....41, 579
Boilers, over heating furnaces.... 171
blast furnace....69, 77
Bounties.... 439
Canadian.... 608
Brown hematite.... 40
Braune, on Sweden.... 593
By-products.... 174

Calorie, value.... 618
Calorific equation of acid converter.... 108
basic converter.... 119
open hearth furnace....148 *et seq.*
Campbell, tilting furnace....132 *et seq.*, 211
Campbell, J. W., on heat treatment.... 274
Canada, iron industry.... 607
statistics.... 615
Cape Breton, iron industry.... 607
Carbo-Allotropic theory.... 311
Carbon, calorific value in converter.... 109
calorific value in open hearth.... 222
combustion of.... 158
determination of.... 31
effect on pig iron....4, 81
effect on steel....22; 343, 368 *et seq.*
effect on wrought iron.... 91
for basic hearths.... 190
in producer ash.... 163
in puddle furnace.... 86
in tool steel.... 97
protective power of.... 180
segregation of....234 *et seq.*
theory (metallography).... 310
Carbon deposition.... 57
Carbonic acid and iron.... 55
in blast furnace....44, 53 *et seq.*
in producer gas.... 165
Carbonic oxide, combustion of.... 158

Cast iron, see pig iron. PAGE
Cast steel 97
Cement carbon 306
Cementation 94
Cement steel 94
Cementite in cast iron..... 83
in steel .....296 *et seq.*
Central Iron & Steel Co., wrought iron..... 89
Charcoal in blast furnace.....42, 571
Charge in open hearth furnace..... 179
Checkers in regenerators..... 126
Chicago, iron industry..... 473
Chromite for basic hearths..... 190
Chromium, effect on physical properties..... 366
Clay iron stone..... 41
Cleveland (England), iron industry.....41, 66 *et seq.*, 700 *et seq.*
Cleveland (U. S.), iron industry..... 491
Coal production 615, 619
Coal fields, see Table of Contents.
Coal washing 178
Cobalt, effect on welding.....91, 403
Coke districts of United States..... 454
exports from N. E. coast (England)..... 507
imports and exports, see Table of Contents.
in blast furnace..... 43
Coke ovens 173
use abroad 422
Combustion, general view..... 158
Colby, on influence of copper..... 361
on influence of nickel..... 365
Colorado, iron industry..... 492
Colored labor in Alabama..... 483
Connellsville, coke.....43, 66 *et seq.*
coke ovens 175
coke and coal industry.....454, 469
Continuous furnaces 172
Cooper, on Northeast Coast..... 503
Copper, effect on welding.....91, 403
in Cornwall ore..... 358
influence on physical properties.....22, 358
Cornwall ore deposit.....484, 495
copper in 358
Crucible steel 7, 94
Crystallization by heat..... 402
Critical point 287
Cuba, ore 41, 358, 447, 488
statistics 447, 615

PAGE
Cuban ore, smelting of.... 59
Cumberland, iron industry.... 517
Cunningham, on segregation.... 240
Cupola castings.... 409
practice.... 110
Custer, on tests of steel.... 326, 340
Cyanogen in blast furnace.... 65

Depreciation.... 437
Derbyshire, iron industry.... 524
Diameter, influence on physical properties.... 322
Direct metal at Steelton.... 142
in open hearth.... 211
in Bessemer.... 108
ore needed.... 224
Dissociation.... 123
Distances in America and Europe.... 441
Dolomite in basic Bessemer.... 9, 113
in basic open hearth.... 15, 190
in blast furnace.... 480
Don, basin of.... 41, 567
Donawitz, iron industry.... 582
open hearth furnace.... 132
Dougherty, on blast furnace.... 53, 61
Dowlais Iron Co., plan of works.... 515, 516
Drillings, method of taking.... 395
Drop of the beam.... 339
Duplex process.... 231
Duquesne, open hearth furnace.... 132
Durham, coal and coke.... 43, 68, 69, 506
Dutreux, iron industry of France.... 553

Edison, on ore concentration.... 495
Ehrenwerth, on acid Bessemer practice.... 111
on open hearth practice.... 186
Elastic limit.... 399
ratio.... 339, 396, 397
Elba, ore.... 605
Elbers, on blast furnace slag.... 51
Electric concentration.... 495
welding.... 406
Elongation.... 20
errors in measuring.... 339
influence of diameter.... 323
influence of width.... 324 *et seq.*
influence of length.... 327 *et seq.*

England, see Great Britain. PAGE
Ensley, Alabama, coke ovens 175
Errors in chemical records 31
Erzberg, ore deposit 582
Eutectic alloy 298
Exports from Sweden 597
of ore from Germany 527
Eye bars, annealing 282
physical properties 314, 316
tests on 330

Felton, on rest after rolling 337
Ferrite in cast iron 83
in steel ..... 296 *et seq.*
Ferro-manganese 8, 12, 82, 350
Ferro-silicon, composition of 81, 83
Findley, on Lake Superior ore 456
Finishing temperature, effect of 302
Firmstone, on dolomite 50
Fluidity of basic slag 197
Flux in blast furnace ..... 49 *et seq.*
use of dolomite 480
Forest of Dean 514
Forgings, physical properties 263, 314
Formulæ for tensile strength ..... 23, 368 *et seq.*
Forter valve 147
France, iron industry ..... 553 *et seq.*
statistics 615
Freights 439
Fuel ..... 158 *et seq.*
Fuel blast furnace 42

Gamma iron 311
Gas, blast furnace ..... 37, 53 *et seq.*
for gas engines 80
for open hearth furnace 123
from basic converter 116
from tunnel head ..... 71 *et seq.*
producer 162
Gayley, on blast furnace 48, 73
German nomenclature 7
Germany, acid Bessemer practice 104
iron industry 525
rolling mill practice 424
statistics ..... 615 *et seq.*
statistics, errors in 609
Gjers soaking pits 170

Gogebic, see Lake Superior. PAGE
Graphite in pig iron 4
Great Britain, competitive factors..... 421
exports of fuel..... 496
imports of ore..... 497
iron industry 496
production by districts..... 498
production of rails..... 445
production of steel..... 445
statistics.....615 *et seq.*
Greece, statistics 615
Grooved tests vs. parallel-sided..... 316
Guide rounds vs. hand rounds..... 268

Hadfield, on effects of aluminum..... 362
on effects of silicon..... 344
on effects of manganese..... 354
on steel castings..... 412
Hand rounds vs. guide rounds..... 268
Harbord, on effect of arsenic..... 363
on basic Bessemer practice..... 120
Hard coal, see anthracite.
Hardening carbon 306
Hartshorne, on Bertrand-Thiel process..... 217
Heating furnaces 170
Heat lost in open hearth furnace.....149 *et seq.*
Heat treatment.....274 *et seq.*
Hematite.....40, 479, 517
Henning, on elastic limit..... 339
on annealing 282
Hibbard, on oxide of iron..... 367
High carbon steel 94
homogeneity of 249
Hofman, on coking..... 150
Holley, on wrought iron..... 90
Hot working, influence of..... 18
Howe, on acid Bessemer..... 103
on carbon deposition 60
on critical point 287
on effect of phosphorus..... 356
on effect of silicon..... 344
on invisibility 286
on micro-metallurgy 299
on structure of pig iron..... 83
on melting point 414
Humidity 47

PAGE
Hungary, iron industry....41, 584
statistics....615 *et seq.*
Hunt, A. E., on influence of methods of manufacture.... 392
on quench test.... 400
Illinois Steel Co., Bessemer practice.... 102
manufacturing plants.... 665
Ilsede, iron industry.... 549
Increments in cost, duplex process.... 232
India, statistics.... 615
Influence of elements on steel....21, 343
Ingot iron.... 93
Ingot steel.... 93
Inspection....27 *et seq.*
Iron oxide in basic slag.... 196
in open hearth.... 214
Iron, primitive methods of making.... 35
Italy, iron industry.... 605
statistics.... 615
Japan, statistics.... 615
Joeuf district.... 557
Johnstown, iron industry.... 483
Jones & Laughlin, blast furnace.... 38
Julian, on Bessemer practice.... 102
von Jüptner, on open hearth practice....149 *et seq.*
on producer work.... 163
Jurugua, mine in Cuba.... 488
Kennedy, Julian, on Russia.... 563
Kertsch, ore beds in Russia.... 569
Kirchhoff, on Cleveland (England) district....504 *et seq.*
on Germany....525 *et seq.*
Kladno, iron industry.... 579
open hearth....216 *et seq.*
Krivoi Rog, ore beds in Russia.... 567
Krupp works.... 541
Labor in Alabama.... 483
in Belgium.... 591
in England.... 421
in Russia.... 564
Labor organizations.... 426
Lahn, iron industry.... 552
Lake Champlain, ore deposits.... 494
Lake Erie, iron industry.... 489
Lake Superior, ore....41, 456
statistics.... 459

Lanarkshire, see Scotland. PAGE
Lancashire hearth 595
iron industry 517
Lash, on open hearth construction..... 125
Laudig, on carbon deposition.....57, 58
Least squares, use of method.....23, 368 *et seq.*
Lebanon, see Steelton.
Ledebur, on blast furnace..... 50
Leicester, iron industry..... 522
Length, influence on physical properties.....327, 335, 399
Lignite in Germany..... 550
in France 561
Lime in basic Bessemer.....114 *et seq.*
in basic open hearth .....191 *et seq.*
in blast furnace .....49 *et seq.*
Limestone in basic open hearth..... 191
in blast furnace .....49 *et seq.*
Limonite 40, 478
Lincolnshire, iron industry..... 522
Liquation of sulphide of manganese..... 201
Liquid interior of ingot, composition..... 253
Longitudinal vs. transverse tests..... 314
Longwy district, France..... 557
Lorraine, see Lothringen.
Lothringen, iron industry..... 527
Lunge, on water gas..... 168
Luxemburg, iron industry..... 527

Magnesia in basic open hearth..... 195
Magnesite for basic hearths..... 190
Magnetic concentration 42
Magnetic properties, effect of heat.....288, 309
Magnetite 41
in United States..... 495
Manganese, allowable content..... 350
determinations of 31
effect on steel.....22, 350, 368 *et seq.*
effect on welding.....403, 408
in acid Bessemer 104, 112
in acid open hearth.....271, 280
in basic Bessemer 117
in basic open hearth..... 201
in blast furnace 82
in steel castings 413
in crucible steel 95
in pig iron 82
in puddle furnace 86

PAGE
Manganese lost in recarburization 188
protective power 180
segregation ..... 234 *et seq.*
use in removing sulphur 201
Manganese steel 354
Markets of the world 423
Martensite ..... 296 *et seq.*
Martin, on micro-metallography 303
Maryland Steel Co., see Sparrows Point.
Bessemer plant 100
coke ovens 175
rail manufacture 305
Mason, on German statistics 609
Menominee, see Lake Superior.
Mesabi, see Lake Superior.
carbon deposition 57
Method of least squares ..... 23, 368 *et seq.*
Metric system 618
Meurthe et Moselle 553
Microscope, use of on steel ..... 296 *et seq.*
Middlesbrough, see Cleveland.
Mill cinder 89
Minette district 40, 41, 528, 530, 553
Mixer, see Receiver.
Monell, on open hearth practice 230
on Russia 563
Moravia, iron industry 580
Muck bar 6, 85

Natal, statistics 615
Natural gas 167, 470
Neutral joint 190
Newfoundland, ore 41, 607
New England, iron industry 494
New Jersey, iron industry 42, 494
New South Wales, statistics 615
New York, iron industry 42, 494
Nickel, effect on physical properties 23, 364
effect on welding 91, 403
Nickel steel, homogeneity of 250
de Nimot, on Belgium 587
Nord district, France 558
Northeast Coast (England), iron industry 503
Northamptonshire, iron industry 522
Norway, iron 600
Nottingham, iron industry 522

Oberschlesein, see Silesia. PAGE
Odelstjerna, on effect of aluminum..... 362
on open hearth practice..... 186
Oil, as fuel..... 167
Oolite 40
Open hearth furnace.....11, 122, *et seq.*
furnace, with natural gas..... 470
process, acid.....12, 179
process, basic 190
metal for rails 393
metal for tool steel..... 97
manufacture in United States.....207, 446
Ore, see Statistics.
cost of transportation..... 463
imported into United States..... 447
in acid open hearth furnace.....13, 182, 184
in basic open hearth furnace..... 192
in Bessemer converter 224
international trade 611
reduction, absorption of heat..... 224
supply of, America 457
supply of, world 613
Osnabruck, iron industry..... 551
Oswald, on Germany..... 536
Otto Hoffman, coke ovens.....175, 177
Overheating, see Heat Treatment.
Oxidation in open hearth..... 224
Oxide of iron, effect on physical properties..... 366
reactions in blast furnace.....53 *et seq.*
Oxychloride of lime..... 202

Pas de Calais district, France..... 558
Pearlite in cast iron..... 83
in steel.....296 *et seq.*
Peine, iron industry..... 549
Pennsylvania, see Table of Contents.
Pennsylvania Steel Co., see Steelton; see also all tables and tests where other sources of information are not mentioned.
Pennsylvania Steel Co., low phosphorus acid steel..... 208
slabbing mill 260
Petroleum 167
Phase doctrine 311
Phillips, on Alabama..... 477
on blast furnace practice.....50, 51
Phosphorus, allowable content.....356 *et seq.*
calorific value 10
determinations of 31

PAGE
Phosphorus effect on steel....22, 356, 368 *et seq.*
effect on welding....91, 403
in acid open hearth.... 187
in basic open hearth....15, 191, 193
in basic Bessemer 9, 114
in Bertrand-Thiel process 216
in blast furnace 4
in steel castings 413
in tool steel 95
in puddling furnace 86
segregation of....234 *et seq.*
Physical properties, see Chapters XIV and XVI.
Pig and ore process at Steelton....142, 184, 186, 211
Pig iron, see Statistics.
composition 81
international trade 611
manufacture....3, 4, 5
production in leading nations....613 *et seq.*
production, per capita.... 611
Pinget, on France.... 555
Pipes, in castings 413
Pittsburgh, blast furnace practice....66, 67, 70
iron industry 468
Plates, rolled from ingots....18, 259
rolled from slabs....18, 260
physical properties 259
tests on 398
Poland, iron industry.... 573
Pomerania, iron industry.... 552
Ports, open hearth furnaces.... 144
Possession works in Russia.... 572
Pourcel, on segregation....237 *et seq.*
Preliminary tests....318, 369
Producers 160
Products of combustion.... 159
Production, see Table of Contents.
of steel in United States.... 444
of steel in Great Britain.... 445
Protective power of elements.... 180
Puddling furnace 5, 85
Pueblo, steel plant.... 492
Pulling speed, effect on physical properties....341, 342
Pyrometer 284, 285

Quench test 400

PAGE
Radiation, loss from, in open hearth 152
Rails, method of rolling 304
of open hearth steel 393
Railways, miles of 423
Raw coal in blast furnace 43, 512
Recarburizer, function of 8, 350
in acid Bessemer 112
in basic Bessemer 120
in acid open hearth 188
in basic open hearth 205
Red hematite 40
Reduction of ore, heat absorption ..... 219 *et seq.*
in open hearth furnace 184, 329
Regenerative furnaces 11, 122, 170
Removal of slag in open hearth 204, 211
Rephosphorization in basic Bessemer 120
in basic open hearth 205
Rest after rolling 337
Reverberatory furnaces 170
Reversing valves, open hearth furnace 144
Richards, R. H., on blast furnace phenomena 60
Riley, on effect of nickel 364
on effect of work on steel 258
Roberts-Austen, on micro-metallurgy 299
Rounds, influence of diameter 322
Royal Prussian Institute, welding tests 406
Ruhr, iron industry 537
Russia, iron industry 563
ore 41
statistics ..... 615 *et seq.*

Saar, iron industry 547
Sandberg, on influence of silicon 349
Saniter, on use of oxychloride of lime 202
Sauveur, on micro-metallurgy 299
Saxony, iron industry 550
Schönwalder, open hearth furnace 131
Schrödter, on German statistics 609
on Germany 525, 542
Scotland, coal in blast furnace 43
iron industry 511
Seebohm, on crucible steel 94
Segregation ..... 17, 19, 234 *et seq.*
Semet Solvay coke ovens 174, 175, 176
Sensible heat in producer gas 164
Shape of test-piece, effect of 19, 25

PAGE
Sharon, open hearth furnace 126
Sheffield, see South Yorkshire.
Shenango Valley 468
Shock, influence on physical properties 352, 353
Shoulders, effect on test-pieces 316
Siegen, iron industry 550
Silesia, iron industry, Germany 544
iron industry, Austria 580
Silica in basic slags 198
in open hearth furnace 227
Silicon, calorific value in converter 8, 109
calorific value in open hearth 221
change of affinity with temperature 103
determinations of 31
effect on steel 22, 344
effect on welding 91, 403
in acid converter 103, 111
in acid open hearth 180
in basic converter 114
in blast furnace 81
in steel castings 413
in crucible steel 95
in puddling furnace 85
protective power of 180
Silico-spiegel, composition of 83
Sink heads 26
Sjögren, on Austria 576
Slag, phosphorus in acid 103
acid Bessemer 105
acid open hearth 12, 183
automatic regulation 17
basic Bessemer 115
basic open hearth ..... 193 *et seq.*
blast furnace ..... 44 *et seq.*
effect on welding 584
removal of, in open hearth 211
in wrought iron ..... 129 *et seq.*
Snelus, on influence of silicon 340
on use of oxychloride of lime 202
Soaking pits 170
Soft coal, see Bituminous Coal.
Soot, in producer gas 162
Sorbite ..... 296 *et seq.*
South African Republic, statistics 615
South Russia, iron industry 567
South Wales, iron industry 514

PAGE
South Yorkshire, iron industry..... 520
Spain, iron industry.....41, 601
statistics 615
Spanish ore, composition and cost..... 508
in Germany 540
in Great Britain..... 515
Sparrows Point, iron industry..... 485
rail exports 489
Spathic ore 41
Specific heat of gases..... 618
Specifications on steel.....24, 394
Speed of testing machine, influence of.....330, 342
Spiegel, composition of 82, 83
use of 8, 350
Stable basic slags 200
Stafford, on open hearth ports..... 144
Staffordshire, iron industry..... 521
Standard test-pieces 399
Statistics.....615 *et seq.*
Stead, on effect of arsenic..... 364
on micro-metallography 306
on use of oxychloride of lime..... 202
Steam in producer gas..... 123
Steel, see Statistics.
definition 6, 94
castings 26, 409
Steelton, iron industry..... 483
Stoves, blast furnace.....3, 37 *et seq.*
Structural work, use of soft steel..... 396
Structure of steel, theories..... 310
Styria, iron industry.....41, 582
Sub-carbide theory 312
Sulphur, determinations of..... 31
effect on steel.....22, 355, 368 *et seq.*
in acid open hearth..... 187
in basic Bessemer 117
in basic open hearth..... 200
in blast furnace.....4, 49 *et seq.*
in Cornwall ore 484
in crucible steel 95
in producer gas 123
in puddle furnace 86
in steel castings 413
in Talbot furnace 215
Sweden, Bessemer practice.....104, 108
crucible steel 98

PAGE
Sweden, iron industry 41, 593
Swedish ingots, segregation 255

Tafna, ore 41
Talbot process 213
Tar in producer gas 162
Tariff question 435
Temperature, determination of 285
effect on combustion of silicon 103
of Bessemer converter 108
of blast furnace ..... 45, 71 *et seq.*
of melted steel 414
of puddle furnace 88
of open hearth furnace 146
Test-pieces, method of taking 19, 313
steel castings 414
Thickness, effect on physical qualities 257
Tilting furnaces 132, 211
Titanium, protective power of 180
ores containing 42
Transferred steel ..... 207 *et seq.*
Troostite ..... 296 *et seq.*
Tropenas process 26, 412
Tucker, on effect of arsenic 363
Tunnel-head gases ..... 3, 37 *et seq.*
Tungsten, effect on physical properties 364
Turner, on influence of silicon 347

Union Bridge Co., eye bars 330
United States, iron industry 441
statistics ..... 442 *et seq.*, 615 *et seq.*
Unstable basic slags 200
Urals, iron industry 570

Valves, open hearth furnace 144
Vermilion, see Lake Superior.
Virginia, iron industry 441

Wahlberg, on segregation 31, 98, 254
Wales, see North Wales and South Wales.
Washed metal 207
Washing of coal 178
Waste gases from heating furnaces 171
heat lost in open hearth 152
in blast furnaces ..... 70 *et seq.*
Water gas 165
Water vapor in air ..... 47 *et seq.*